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A STUDY OF THE EFFICIENCY OF THE USE OF PESTICIDES IN AGRICULTURE

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A Study of the Efficiency of the Use of Pesticides in Agriculture

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sorghum
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miticides
fumigants
plant growth regulators
application
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A STUDY OF THE EFFICIENCY OF THE USE OF PESTICIDES IN AGRICULTURE

By

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PREFACE

This report describes the results of a study conducted jointly by Midwest Research Institute (MRI) and RvR Consultants during the period 1 August 1974 to 14 February 1975. The study was performed for the Strategic Studies Unit, Office of Pesticide Programs, U.S. Environmental Protection Agency (EPA), under Contract No. 68-01-2608, entitled "A Study of Wasteful Pesticide Use Patterns." The EPA Project Officer was Mr. Allan Zipkin.

Work on this program (MRI Project No. 3949-C; RvR Project No. 67) was conducted with Dr. Rosmarie von Rümker as task leader. The program was under the general supervision of Dr. H. M. Hubbard, Director of MRI's Physical Sciences Division, and Dr. E. W. Lawless, Head, Technology Assessment Section. The MRI project members consisted of Mr. Gary Kelso, Group Leader; Miss Kathryn Lawrence; and Mr. Francis Bennett. Dr. Arthur Allen acted as consultant to the program. The RvR project members were Dr. Rosmarie von Rümker and Mrs. Freda Horay.

Approved for:

MIDWEST RESEARCH INSTITUTE

H. M. Hubbard, Director
Physical Sciences Division

2 July 1975

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ABSTRACT

A study was made of the efficiency of the use of pesticides to identify and quantify the wastes and losses which occur in the treatment of agricultural crops. The study was reported in two volumes. The first volume identified the management practices and decisions for three crops--corn, sorghum, and apples--that may lead to wasteful pesticide use, and quantified the pesticide wastes occurring on each crop as a result of these management practices. The second volume identified the physical factors that cause pesticide waste and losses both during and after crop treatment for agriculture in general, and estimated the application and postapplication pesticide losses and wastes that occurred in 1971 for each of the three above crops. The physical factors which were examined extensively in this study were pesticide overapplication and nonuniform distribution, pesticide drift, and pesticide losses from crops due to runoff and soil erosion.

SECTION I

INTRODUCTION

BACKGROUND

The use of pesticides in the agricultural sector of our society is often required for the effective production of food and fiber. Crops have to compete with weeds, insects, fungi, nematodes and other pests which would decrease yield quantity and/or quality if left uncontrolled. Pesticides are also employed against insects and other pests threatening human health or comfort, or destroying structures, stored products, etc.

Controlling the pests that attack food crops is a monumental and ever-increasing problem. Throughout the world there are 18,000 species of weeds, 1,800 of which cause annual economic losses. Each major crop is infested with between 10 and 50 different weeds, and most cultivated crops are subject to infestation from about 200 weed species. There are over 10,000 species of pest insects, 50,000 species of fungi causing 1,500 different diseases, and more than 1,500 species of nematodes that can damage and destroy crops. Despite the advanced pest control technology available today, these pests cause losses amounting to about one-third of the potential agricultural production each year.

Though pesticides have become necessary to assist man in meeting vital health and nutritional needs, they can be damaging as well as beneficial to both man and his environment. To minimize the cost and maximize the benefits of pesticides to society as well as to the individual user, pesticides must be used in the most efficient and effective way possible. Unfortunately, not all of the quantities of pesticides used in agriculture are employed in this manner. Unnecessary or otherwise nonbeneficial uses of pesticides and unwanted, avoidable discharges of pesticides into the environment are wasteful economically as well as ecologically.

The U.S. Environmental Protection Agency has been charged by the Congress to regulate pesticides in such a manner that the economic, social, and environmental costs of their use do not exceed benefits. In carrying out this mandate, the Agency is interested in promoting the most effective and efficient use of pesticides where they are needed, and in assisting farmers in protecting their crops from pests at minimum cost to themselves and to society. The objective of avoiding pesticide wastage and losses has assumed increased priority and urgency as a result of the energy crisis. Many pesticides are petroleum-based chemicals. The production, formulation, distribution and application of all pesticides consumes additional energy. On the other hand, control of pests by other conventional methods may require more labor, larger amounts of fuel for farm equipment, or other costs.

This study deals with the efficiency of the use of pesticides. Here, efficiency is used in the sense of being inversely related to wastage and losses of pesticides, and our study excluded energy considerations. The study focused on the identification and quantification of avoidable pesticide wastes and losses that cause unnecessary costs to users as well as to society, without offsetting benefits.

OBJECTIVES

The major objectives of this study were:

- To define and identify pesticide wastes and losses.
- To identify and evaluate wasteful pesticide use practices on selected agricultural crops.
- To identify and evaluate avoidable pesticide losses during and after application.
- To quantify avoidable pesticide wastes and losses in as much detail as possible.

STUDY APPROACH

To accomplish these objectives, this project was divided into the following four major tasks which were conducted under a joint effort by MRI and RvR Consultants.

Task 1 - Select Suitable Crop/Pest/Pesticide Systems for Detailed Study

Many of the parameters of pesticide use cannot be studied in a broadly general way, but only as they apply to specific crop/pest/pesticide systems. Several criteria were considered and evaluated in order to select three study crops; these included volume of pesticides used on the crop, crop acreage, crop farm value, and existence of integrated pest management programs on the crop. A numerical rating system was developed (see Appendix A, Table A-4), and the crops which rated highest were: (a) corn; (b) cotton; (c) the conglomorate category of vegetables; and (d) soybeans. Other crops that ranked high, but with some variation in order depending on the criteria used, were sorghum, apples, and wheat.

Cotton was dropped from further consideration because it is already the subject of several other studies. Sorghum was selected ahead of soybeans because of pesticide use patterns and the greater number of integrated pest management studies on sorghum. Apples were selected ahead of vegetables since no single vegetable species appeared to be as suitable as apples. Therefore, the crops selected for study were: (a) corn; (b) sorghum; and (c) apples.

The detailed data and considerations on which this choice of study crops were based were developed by RvR Consultants and are included in this report as Appendix A.

Task 2 - Define and Identify Pesticide Wastes and Losses

Our search of the literature failed to produce any publications in which pesticide wastage and losses have been defined, analyzed and categorized systematically. This was therefore an important requirement early in the project. An initial set of definitions was developed by the project team and then further improvements and refinements were made in consultation with the EPA project officer. The results of these efforts are presented below in the section on "Definitions and Identification of Pesticides Wastes and Losses."

The categorization of pesticide wastes and losses indicated several different principles by which the subsequent tasks might be organized. For several reasons, we have structured our studies along two general themes: (a) pesticide wastage due primarily to management decisions before application, and (b) pesticide losses due primarily to physical factors during and after application.

One of the major reasons for this structure is that wastage of pesticides due to management decisions before application differs greatly among different crops, pests, types of pesticides, and geographic regions, so that generalizations or extrapolations to or from other crops, pests, types of pesticides or regions cannot be made. By contrast, findings in the area of pesticide losses during or after application due to physical factors may apply to crops, pesticides or regions other than those studied if the physical and environmental conditions of the pesticide use are sufficiently similar. Thus, investigations on drift, runoff and other aspects of pesticide losses due primarily to physical factors were useful in Task 4 regardless of the crop involved, while in Task 3, our investigations had to focus on the three selected crop/pest/pesticide systems, and our findings apply only to them.

Task 3 - Identify and Evaluate Wasteful Pesticide Use Practices on the Three Selected Study Crops

This task was carried out primarily by RvR Consultants with MRI furnishing some of the statistical data for the crop pesticide usage and crop acreages. For each of the study crops, the use patterns of herbicides, insecticides, miticides, fungicides and other pesticides were studied in relation to the need for treatment. Management factors that might contribute to nonbeneficial uses of pesticides were investigated. Special attention was given to pesticide application rates and frequency of application as:

* Specified in the registered label of the product;

* Recommended by the Federal/State Cooperative Extension Service;

* Recommended by other crop protection advisors;

* Commonly used by growers;

* Required for economic pest control; and

* Used in integrated pest management programs (where applicable).

In line with the objective to quantify pesticide wastage and losses in as much detail as possible, quantitative aspects received prime attention throughout this phase of the study.

The data and information needed in this task were obtained from a variety of sources, including a thorough search of the literature and interviews with experts such as public and private crop protection advisors, growers, and other knowledgeable persons. Some of these interviews were conducted by telephone, others in person in the field and at several recent scientific meetings.

Furthermore, a limited mail survey was conducted of extension entomologists, weed scientists, and plant pathologists working in the leading corn, sorghum, and apple producing states. The results of this survey were also helpful to the project.

Task 4 - Identify and Evaluate Avoidable Pesticide Wastes and Losses Occurring During and After Application

This task was carried out by MRI. The study examined the problem of pesticide wastes and losses occurring during and after application. The approach taken to this aspect of the study is given in Section VIII.

SECTION II

DEFINITION AND IDENTIFICATION OF PESTICIDE WASTES AND LOSSES

EFFICIENT USE OF PESTICIDES

This study deals with the problem of efficiency in the use of pesticides. According to contemporary dictionaries, "efficient" is broadly defined as "producing the desired effect or result with a minimum of loss or waste."

When pesticides are used in agriculture, the desired effect usually is to prevent a yield loss (quantity and/or quality) that pests would cause if left uncontrolled. Maximizing efficiency in the use of pesticides requires minimizing pesticide wastes and losses; wastes and losses are inversely related to efficiency.

PESTICIDE WASTES AND LOSSES

Pesticide wastes and losses may be categorized by a number of different criteria which are partly overlapping. These include:

* Avoidability (some wastes and losses are avoidable, some are not);

* Type of waste or loss (unnecessary use, overuse, misuse, etc.);

* Cause of waste or loss (management decisions, physical factors);

* Relationship to time of application (before, during, after); and

* Quantity of pesticide involved.

These different aspects of pesticide wastes and losses and their interrelationships require some further definition and discussion.

AVOIDABLE VERSUS UNAVOIDABLE PESTICIDE WASTES AND LOSSES

Pesticide Wastage

For purposes of this study, pesticide wastage, or wasteful use is defined as unnecessary use, overuse or misuse of pesticides. Every application of a pesticide is preceded by someone's decision to make that application. At that decision point, wasteful pesticide uses could be avoided by a decision not to make an unnecessary application, or not to apply the pesticide at an unnecessarily high rate. Therefore, most or all wasteful pesticide uses are avoidable in principle. (It is recognized, of course, that things are not that simple in practice because decision-makers often have no certain way of knowing whether a given pesticide use is necessary or not, or whether a given rate of application is too high, too low, or just right.)

Pesticide Losses

For purposes of this study, pesticide losses are defined as unwanted pesticide deposits, or pesticide quantities that do not reach the intended target and, therefore, do not contribute to accomplishing the purpose of the application. In most pesticide uses, very little of the pesticide applied actually reaches the site of action within the target pest. Thus, by this very broad definition, a large percentage of all pesticides is "lost."

A schematic description of the possible fate of a given quantity of insecticide sprayed topically on a crop for insect control is helpful in illustrating the situation (Figure 1, taken from a recent report by von Rümker et al., 1974*). The percentage loss figures (in terms of the quantity applied = 100%) do not represent one specific case, but were composited from several field studies. Typical losses due to drift were taken from the studies by Adair et al. (1971), Akesson and Yates (1964), and Brazzel et al. (1968). Losses due to surface runoff from the target area were composited from the studies by Caro et al. (1973), Ritter et al. (1974), and White et al. (1967). Information on the propensity of pesticides for volatilization and leaching has been reported by von Rümker and Horay (1972). Furthermore, it was assumed that the degree of ground cover of the target crop in the target area is 75%, and that not more than 10% of the insecticide quantity impacting on the target crop will impact near target insects. Of the quantity impacting near target insects (4% of the applied rate), only a small portion will actually be absorbed by the target insects through contact, inhalation, and/or ingestion. Thus, ultimately, only a very small fraction of the quantity applied (much less than 1%) will reach the site of toxic action inside the target insect.

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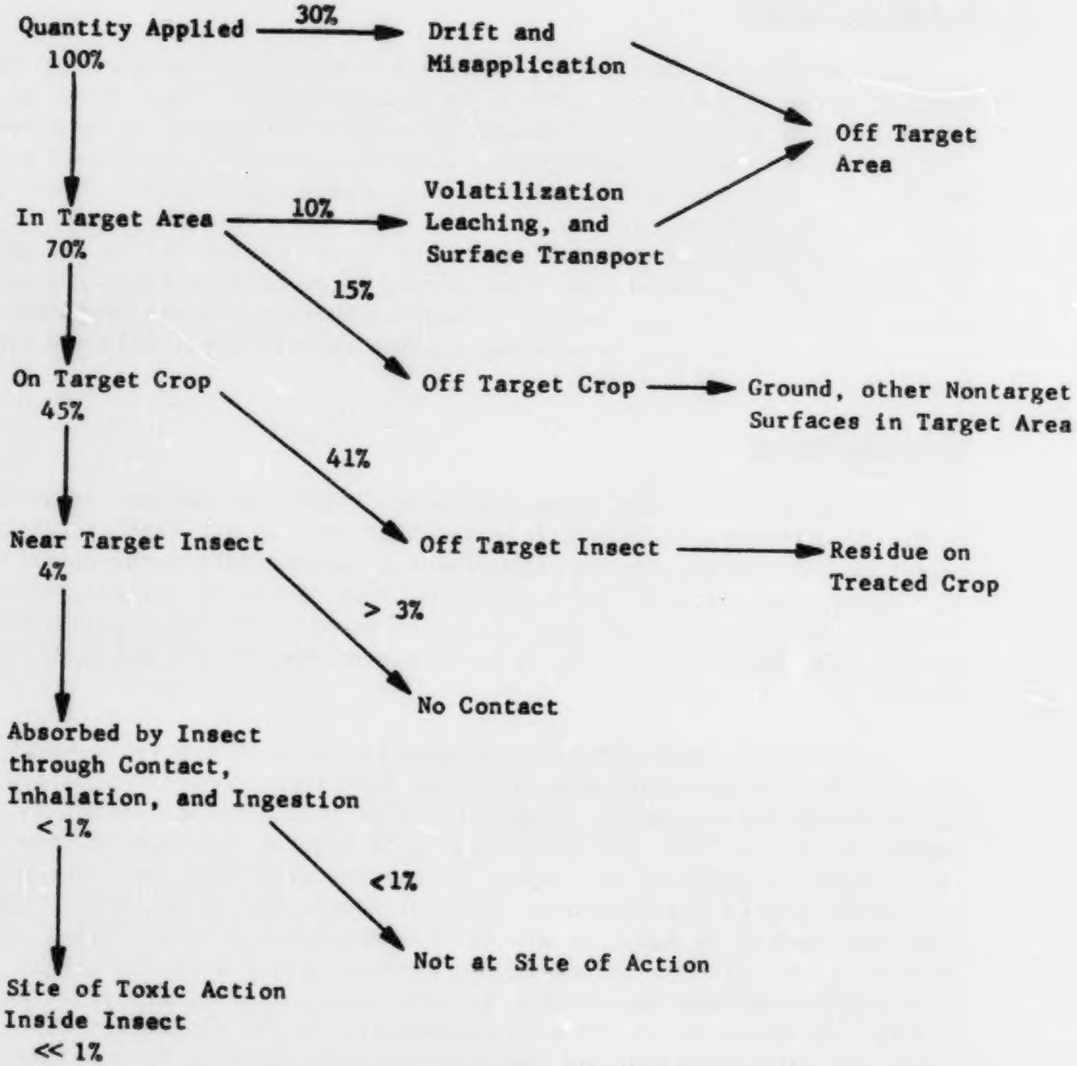
* References are given at the end of each section of this report.


Quantity Applied
100%
30%
Drift and
Misapplication
Off Target
Area
In Target Area
70%
10%
Volatilization
Leaching, and
Surface Transport
15%
On Target Crop
45%
Off Target Crop
Ground, other Nontarget
Surfaces in Target Area
41%
Near Target Insect
4%
Off Target Insect
Residue on
Treated Crop
> 3%
No Contact
Absorbed by Insect
through Contact,
Inhalation, and Ingestion
< 1%
<1%
Not at Site of Action
Site of Toxic Action
Inside Insect
<< 1%

Percentage distribution figures do not represent one specific case, but are composited from several different field studies and assumptions on the degree of ground cover and the density of target insects on the target crop.
Source: Report published by von Rümker, Lawless, and Meiners (1974), p. 108.

Figure 1. Aerial foliar insecticide application: typical losses between spray nozzle and site of toxic action.

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Under field conditions, the rates of pesticide losses at each step may vary greatly, depending upon all elements in the system and their interrelationships, including the physical factors discussed in greater detail in other sections of this report. Regardless of how these factors interact, however, frequently only a very small fraction of the insecticide applied becomes effective for the intended purpose, i.e., controlling the target pest. Shaw and Jansen (1972) presented a similar mass balance for herbicide use. Mass balances for other types of pesticide uses, such as fungicides or soil insecticides, may be somewhat different, but they may also be quite inefficient if evaluated in this manner.

Thus, large quantities of chemical pesticides could be saved, and unwanted residues on treated crops and in the environment could be reduced, without sacrificing benefits, if the pesticide's route from the application equipment to the site of action inside the target pest could be made more efficient and less wasteful. Unfortunately, however, at the present state of pest control technology, a large percentage of the pesticide losses depicted in Figure 1 are unavoidable and cannot, therefore, be considered to be wasteful in a practical, operational or economic sense. These facts suggest the need for research aimed at improving the efficiency of pesticide application systems, and at the development of technologies for more efficient, less wasteful delivery of pesticides to their targets.

Our investigations in this project deal primarily with avoidable pesticide wastes and losses. Among the loss mechanisms depicted in Figure 1, drift, misapplication, and surface transport (runoff) are at least in part avoidable. These loss mechanisms were studied and are reported in Volume II of this report.

TYPES, CAUSES AND OTHER CHARACTERISTICS OF AVOIDABLE PESTICIDE WASTES AND LOSSES

For purposes of this study, avoidable pesticide wastes and losses are considered to include four major routes of waste. These categories, their definitions, underlying causative factors, relationship to time of application, and the quantities of pesticides likely to be involved are as follows.

Unnecessary Use

No treatment required, i.e., use of a pesticide in the absence of an established need to control or suppress the target pest(s).

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Examples:

- * Use of pesticides in preprogrammed application schedules based on the calendar instead of actual need.
- * "Insurance"-type applications made regardless of need.

Unnecessary pesticide uses result from management decisions. Every application of a pesticide is preceded by a decision to make that application. Unnecessary applications are avoidable by a decision not to apply. Unnecessary pesticide uses may involve substantial quantities of pesticides. Therefore, the question if and to what extent pesticides are used unnecessarily received primary attention in our evaluation of pesticide use patterns on corn, sorghum, and apples (Section V, VI and VII). This question cannot be studied or answered in general terms, but only in relation to specific crops, pests, and pesticides, as the findings detailed below demonstrate.

Overuse

Too high a rate, i.e., use of a pesticide at a rate of application higher than necessary for the intended pest control or suppression purpose.

Examples:

- * In many instances, insecticides provide economic control of target pests at rates of application much lower than those required for 99 to 100% kill. When applied at high rates, insecticides often destroy beneficial predators and parasites that would help to suppress pest insects and mites. When their natural enemies are destroyed, these secondary pests may then build up to damaging proportions that require additional applications of chemical insecticides or miticides. Thus, application of insecticides at higher rates than necessary for economic control of target pests is often biologically as well as economically wasteful, and sometimes even counterproductive.
- * Pesticide overuse may also occur during application as a result of miscalibration of application equipment, driving properly calibrated equipment at a speed slower than that used in calibrating, double treatment of field or orchard borders, excessive overlapping of application swaths, etc.

Pesticide overuse due to selection of too high a rate of application (first example above) results from management decisions prior to application. This type of overuse is avoidable and may involve substantial quantities of pesticides. It was evaluated in detail in the studies of pesticide use patterns on corn, sorghum, and apples (Sections V, VI and VII).

Pesticide overuse during application (second example above) results most often from improper operation of application equipment. This route of waste was examined in our studies on pesticide losses during and after application as reported in Volume II.

Misuse

Use of a pesticide not registered or otherwise not suitable for the intended purpose, or use of a registered suitable pesticide in an unsuitable manner.

Example:

* Selection of the wrong pesticide, wrong target pest, wrong formulation, and/or wrong application method.

Pesticide misuse as defined in the Federal Insecticide, Fungicide and Rodenticide Act and the 1972 Amendments thereto is illegal and may result in prosecution.

Pesticide misuses occur most often as the result of inadvertent errors on the part of persons supervising or making pesticide applications. Such misuses are avoidable or reducible to the extent that human error can be reduced by education, training, supervision, etc. Compared to the other categories of pesticide wastes and losses, misuses do not involve large quantities of pesticides and were not studied in detail in this project. The misuse category is included among the definitions of pesticide wastes and losses for completeness' sake.

Unwanted, Avoidable Discharge, Deposit or Migration

Unwanted, avoidable discharges of pesticides into the environment due to excessive drift or runoff, improper disposal of pesticides or containers, spills, dumping, etc.

Examples:

* Pesticide spills due to puncturing, breakage, tearing or other failure of containers, leakage of tanks or hoppers, leakage or breaking of parts of application equipment, etc.

- * Improper disposal of leftover concentrated or diluted pesticides, or of pesticide containers, especially containers not completely emptied.*

- * Excessive, avoidable drift during application of pesticides due to too small particles, too great distance between nozzle and target, unsuitable weather conditions, etc.

- * Excessive post-application pesticide loss from target areas inherently subject to runoff due to topography of the area, lack of terracing or contouring, etc.

Pesticide losses of this type occur during or after pesticide application. They are avoidable only in part. Pesticide spills occur most often as a result of operating accidents which are mostly uncontrollable and usually involve relatively small quantities of pesticides. Disposal of pesticide containers and of residues in the pesticide application equipment involve substantial quantities of pesticides, but the techniques used to accomplish these tasks are within the control of pesticide users. Any waste involved in inefficient disposal techniques can be resolved through educating pesticide users as to the proper methods of disposal and as to their importance. Therefore, pesticide spills and disposal did not receive detailed attention in this study; they are briefly discussed in Volume II.

Excessive, avoidable drift during application and excessive, avoidable runoff after application involve substantial quantities of pesticide losses throughout agriculture that can be reduced by proper application techniques and conservation methods. These two mechanisms of pesticide loss were studied in detail, as reported in Volume II.

SECTION III

SUMMARY

The results of this study are summarized below in two sections. In the first section, our findings concerning the efficiency of the use of pesticides on corn, sorghum and apples as influenced by pre-application management decisions are set forth. Our studies showed that the use patterns of different types of pesticides (herbicides, insecticides, fungicides, etc.) and the degree of efficiency with which they are used on the three crops varied considerably. The findings reported in this section are applicable only to the crop/pest/pesticide systems studied.

In the second section, our findings on pesticide wastes and losses during and after application are summarized. In this part of the study, our investigations were not limited to corn, sorghum and apples, and many findings may apply to other crops to which pesticides are applied in a similar manner.

EFFICIENCY OF THE USE OF PESTICIDES ON CORN, SORGHUM, AND APPLES AS AFFECTED BY PRE-APPLICATION MANAGEMENT DECISIONS

Table 1 presents an overview of our findings concerning the efficiency of the use of pesticides on corn, sorghum, and apples as affected by management decisions prior to application.

Herbicides are used extensively on corn and sorghum. In the opinion of weed research and extension scientists working with these crops and of corn and sorghum growers, these herbicide uses are essential to the efficient, profitable production of these crops and involve minimal, if any, pesticide wastage. We found no field research data to show whether or not economic weed control in corn or sorghum could be obtained by substantially lower herbicide inputs.

Table 1. ESTIMATED RATE OF TOTAL VS. NEEDLESS USE OF PESTICIDES ON CORN, SORGHUM, AND APPLES

Pesticide	Crop	% of Crop[a] Treated	% of Quantity Applied Used Needlessly	Quantity Used Needlessly[b] (1,000 lb AI)
Herbicides	Corn	90	Small	Small
	Sorghum	70-80	Small	Small
	Apples	Small	Negl.	Negl.
Insecticides[c]	Corn	50	50[d]	12,800
	Sorghum	60-70	50-60[e]	2,900-3,400
	Apples	> 90	20-30[e]	1,040-1,560
Fungicides	Corn	Negl.[f]	Negl.	Negl.
	Sorghum	Negl.[f]	Negl.	Negl.
	Apples	> 90	Small	Small
Other Pesticides[g]	Corn	Negl.	Negl.	Negl.
	Sorghum	Negl.	Negl.	Negl.
	Apples	Small	Negl.	Negl.

---

a/ In the case of corn and sorghum, % of acreage harvested for grain.

b/ Estimated % needless uses applied against total quantities of insecticides (and miticides in the case of apples) used on the three crops in 1971 according to the USDA pesticide use survey.

c/ Includes miticides in the case of apples. No substantial quantities of miticides are used on corn or sorghum.

d/ Needless uses consist primarily of insecticide applications to field not needing the treatment.

e/ Needless uses consist of insecticide applications in the absence of established need for treatment, of applying insecticides at higher than minimum effective rates, and of insecticide or miticide applications necessitated by preceding injudicious pesticide use.

f/ Excluding seed treatment.

g/ Includes fumigants, defoliants, desiccants, plant growth regulators, etc.

Source: RvR Consultants, this study.

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On apples, herbicides are used only in relatively small quantities. We did not find any indications or evidence of wasteful herbicide use on apples.

Insecticides/miticides are used on an estimated 50% of the U.S. corn acreage harvested for grain, on 60 to 70% of the grain sorghum acreage, and on a very high percentage of all apple orchards. As discussed in the sections dealing with insecticide use practices on the three study crops, we estimate that approximately 50% of the quantities of insecticides applied to corn, at least 50% of the insecticides applied to sorghum, and 20 to 30% of the insecticides applied to apples are used needlessly.

In the case of corn, insecticide treatments are applied to many fields that do not need the treatment. In the case of both sorghum and apples, needless uses include insecticide applications in the absence of an established need for treatment, applications at higher than minimum effective rates, and insecticide or miticide applications that become necessary secondarily as a result of preceding injudicious pesticide applications which destroyed naturally present beneficial predators and parasites.

On all three crops studied, an important prerequisite to actually realizing these potential insecticide savings would be the widespread adoption and implementation of integrated pest management procedures.

Only small quantities of fungicides are used on corn and sorghum. Fungicide uses on these two crops were therefore not studied in detail.

Much larger quantities of fungicides are used on apples. Most of the currently available commercial apple fungicides have to be applied on preventive, preprogrammed application schedules for optimal biological and economic effectiveness. No practical nonchemical methods for the control of fungal diseases of apples are currently available to growers, and no "integrated disease management" programs for apples have yet been developed. Thus, apple growers needing to protect their crop against fungal pathogens do not currently have feasible alternatives to the use of chemical fungicides on preventive treatment schedules. There is no evidence of significant wasteful uses of fungicides on apples.

"Miscellaneous pesticides" including fumigants, defoliants, desiccants, plant growth regulators and others are used only in small quantities or not at all on corn, sorghum or apples. Uses of these pesticides were therefore not studied in depth. The limited information obtained in the course of pursuing the project's major objectives does not include any evidence that these "miscellaneous pesticides" are used on corn, sorghum, or apples in a wasteful or inefficient manner.

Our estimates of the quantities of insecticides applied needlessly to corn, sorghum, and apples (Table 1) are expressed in terms of percent of the total quantity applied, and in terms of pounds of active ingredient. The latter estimate was calculated by applying the estimated percent needless uses against the total quantities of insecticides (and miticides in the case of apples) used on the three study crops in 1971 according to the USDA pesticide use survey.

The potential savings in insecticides/miticides shown in Table 1 are not additive to the estimated losses occurring during and after application of pesticides as summarized in Table 37 (page 112). In both tables, the volume estimates are based on the actual uses of the pesticides concerned in 1971, according to the USDA pesticide use survey. If, for instance, 30% of the quantities of insecticides and miticides used on corn, sorghum, and apples in 1971 would be saved as a result of pre-application management decisions to avoid unnecessary use and overuse, then 30% of the estimated losses during and after application shown in Table 37 would not occur in the first place. Additional savings in pesticide quantities by reduction of drift, runoff and other application and post-application wastes and losses would affect only the remaining 70% of the quantities of these pesticides.

PESTICIDE WASTES AND LOSSES OCCURRING DURING AND AFTER APPLICATION

The results and findings of this part of the study are given in Volume II of this report since the material presented is both technical and extensive. The study approach, the study areas, and a summary of the results and findings of Volume II are presented in Section VIII of this volume. For a summary of the work done in this aspect of the study, the reader is referred to Section VIII, page 106.

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

No evidence was found in this study, given the present state of pesticide and pest management technology, that herbicides, fungicides, fumigants, defoliants, desiccants, plant growth regulators and pesticides other than insecticides and miticides are used on corn, sorghum, or apples in an inefficient or wasteful manner. Our findings regarding the use patterns of insecticides and miticides lead to the conclusion that approximately 50% of the quantities of these pesticides currently used on corn and sorghum, and 20 to 30% of the quantities used on apples are used needlessly. At least in part, this is due to the fact that in practice, persons recommending or making pesticide applications often have no certain way of knowing whether a given pesticide use is necessary or not, or whether a given rate of application is too high, too low, or just right.

Reductions in the quantities of insecticides and miticides used on corn, sorghum, and apples approaching 50% would require widespread adoption and implementation of integrated pest management practices, and greatly improved understanding and acceptance of integrated pest management principles and procedures by persons making pest management decisions and pesticide applications.

Thus, a percentage of the quantities of chemical insecticides and miticides used on the three crops is replaceable by integrated pest management. To the degree that chemical insecticides and integrated pest management services are interchangeable, they compete for the same users and dollars.

It does not follow, however, that the pesticide industry and integrated pest management proponents have to be in adversary positions. It would seem to be in the best interest of all concerned, industry, growers, as well as society as a whole, to reduce avoidable wastes and losses of pesticides, and to use these chemicals as efficiently and effectively as possible.

Growers need the best and most economical crop protection, not necessarily large quantities of inexpensive pesticides. The pesticide industry needs a larger operating profit per pound of chemical produced if it is to develop and market more selective pesticides that will be used in smaller quantities. No one wants avoidable, nonbeneficial pesticide residues in the food supply, in the environment, or any place else.

Integrated pest management experts and practitioners are an important element in improving all aspects of crop protection, including efficiency in the use of chemical pesticides.

RECOMMENDATIONS

* Promote further development and implementation of integrated pest management methods and practices.

* Remove legal obstacles to the recommendation and use of pesticides in integrated pest management programs at rates of application lower than those registered by the manufacturer.

* Promote cooperation among all concerned (including government agencies, universities, the pesticide industry, integrated pest management practitioners, and growers) in the development and implementation of better crop protection and pest management systems, including more efficient use of chemical pesticides.

Substantial quantities of pesticides are lost during and after application to corn, sorghum, and apples, and probably many other crops as well. Unwanted overapplication, nonuniform distribution, drift, and runoff are among the most significant loss mechanisms. Wastes and losses of pesticides during and after application due to these factors are avoidable only in part at the present state of pesticide and equipment technology. In addition, efforts to reduce pesticide losses from one of these mechanisms may increase losses from another. For instance, coarse sprays produce less drift, but may require more pesticide to produce the desired degree of plant coverage and control of the target pest. Coarse sprays also are more likely to result in nonuniform distrubution of droplets and uneven rates of pesticide deposits in the target area.

RECOMMENDATIONS

- Promote development of pesticide application methods and equipment that will reduce pesticide wastes and losses during application, in particular, overapplication, nonuniform distribution, and drift.

- Promote soil conservation practices that will reduce post-application pesticide losses due to runoff and erosion.

SECTION V

PESTICIDE USE PATTERNS ON CORN

PRODUCTION OF CORN IN THE UNITED STATES

In terms of total acreage and farm value, corn is the leading agricultural crop in the United States. In 1974, 77.4 million acres were planted to field corn, that is about 25% of the total U.S. harvested cropland acreage, and 3.4% of the total land area of the United States (including Alaska).

Table 2 summarizes the U.S. corn acreage, yield, value, and production during the last 4 years, 1971 to 1974. The corn acreage planted for all purposes ranged from a low of 67 million acres in 1972 to a high of 77.4 million acres in 1974. In each of the 4 years covered in Table 2, about 85% of the total corn acreage planted for all purposes was harvested for grain.

Table 2. U.S. CORN ACREAGE, YIELD, VALUE AND PRODUCTION, 1971 TO 1974

Acreage, yield value, production	Year			
	1971	1972	1973	1974
Acreage planted for all purposes, 1,000 acres	74,055	64,000	71,600	77,400[b]
Acreage harvested for grain, 1,000 acres	64,047	57,421	61,760	63,746[b]
Yield,[a] bu/acre	88.1	97.1	91.4	72.5[b]
Average farm price, $/bu	1.08	1.57	2.55	3.45[c]
Farm value, $/acre	95.15	152.45	233.07	250.13[b]
Total production, million bushels	5,641	5,573	5,643	4,621[b]

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a/ Yield per acre harvested for grain.
b/ Preliminary.
c/ October 1974.
Sources: U.S. Department of Agriculture (1973, 1974a, c).

Corn yields (per acre harvested for grain) during this period ranged from a record high national average of 97.1 bu in 1972 to a low of 72.5 bu in 1974. The average price of corn received by farmers increased from $1.08/bu in 1971 to $1.57 in 1972, and to $2.55 in 1973, an increase of 136% over this 2-year period. Average farm prices for the 1974 crop are not available at this writing (January 1975). The October 1974 farm price for corn was $3.45/bu, compared to $2.17/bu in October of 1973, and $1.19/bu in October of 1972.

The farm value per acre of corn harvested for grain increased from $95.15 in 1971 to $152.45 in 1972, and further to $233.07 in 1973, an increase of 145% from 1971 to 1973. Indications are that in spite of the disappointing corn yield in 1974 due to unfavorable weather, the farm value per acre of corn for grain will be even higher in 1974 than it was in 1973.

Figure 2 presents the U.S. Department of Agriculture's division of the United States into 10 regions.

The total production of corn in the U.S. was about 5.6 billion bushels in 1971, 1972, and 1973, dropping to 4.6 billion bushels in 1974.

Figure 3 presents a breakdown of the U.S. corn acreage planted for all purposes in 1971. Table 3 summarizes the U.S. acreage of corn for grain by major producing states for the last 3 years, 1972 to 1974, showing state totals for all states growing more than 1 million acres in decreasing order of number of acres grown in 1974, and subtotals for the Corn Belt States. In 1974, the five Corn Belt States (Iowa, Illinois, Indiana, Ohio, and Missouri) raised 33.9 million acres of corn for grain, that is 53.1% of the national total. All other states growing more than 2 million acres of corn for grain were also midwestern states, i.e., Minnesota, Nebraska, South Dakota, and Wisconsin. The five Corn Belt States and the six other major midwestern corn-producing states combined raised 52.2 million acres of corn for grain in 1974, that is 82% of the U.S. total.

These data document that while some corn is grown in practically every state in the Union, the production of this crop is heavily centered in the midwestern states.

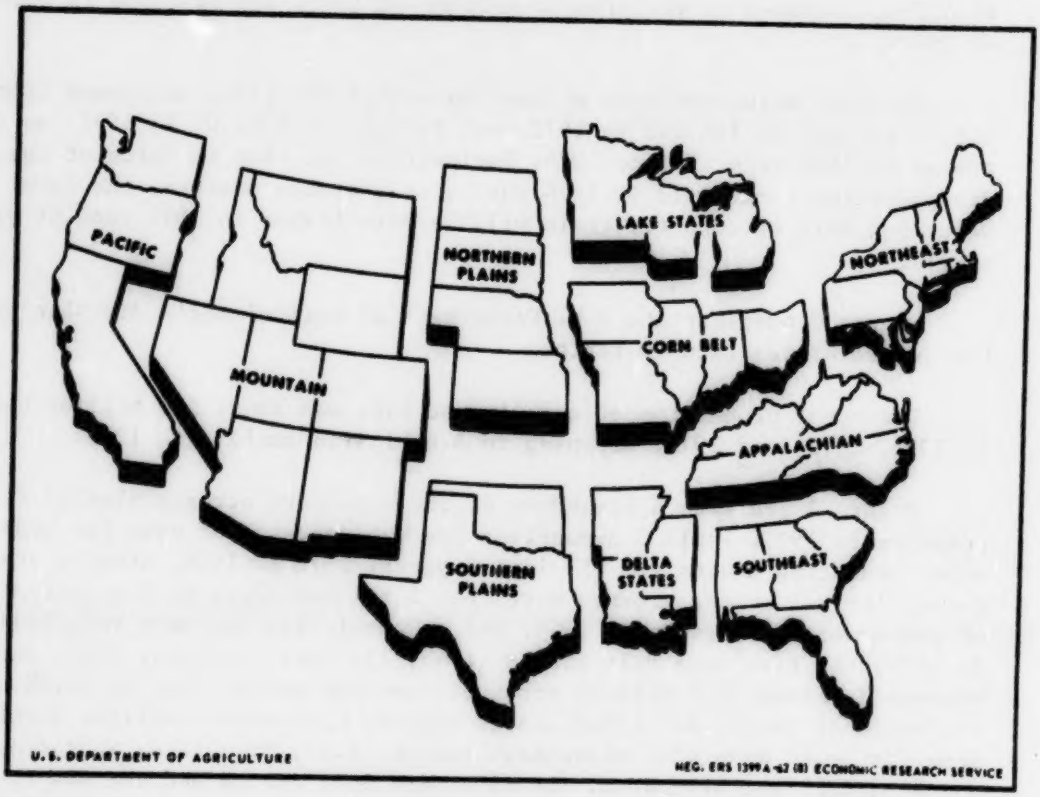
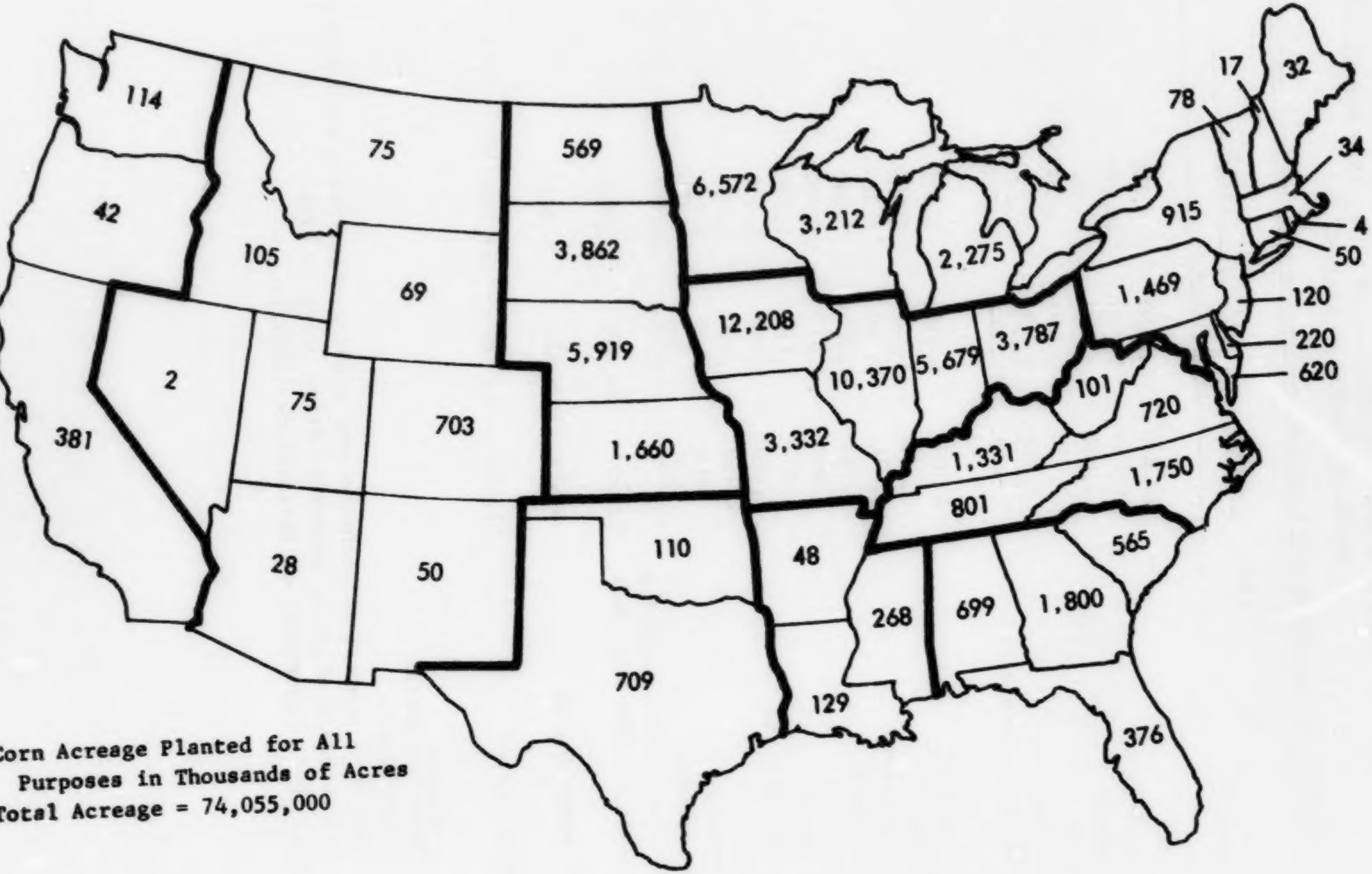

PACIFIC
MOUNTAIN
NORTHERN PLAINS
LAKE STATES
CORN BELT
NORTHEAST
APPALACHIAN
SOUTHERN PLAINS
DELTA STATES
SOUTHEAST
U.S. DEPARTMENT OF AGRICULTURE
NEG. ERS 1399A-62 (8) ECONOMIC RESEARCH SERVICE

Figure 2. Farm production regions.


114
75
569
6,572
3,212
2,275
78
17
32
34
915
4
50
42
105
69
3,862
5,919
12,208
1,469
120
220
620
3,787
5,679
10,370
2
75
703
1,660
3,332
101
720
381
1,331
1,750
801
565
28
50
110
48
268
699
1,800
709
129
376

Corn Acreage Planted for All
Purposes in Thousands of Acres
Total Acreage = 74,055,000

Figure 3. U.S. corn acreage (1971), by state.

Table 3. CORN ACREAGE[a] IN THE U.S. IN 1972, 1973 AND 1974[b] BY MAJOR PRODUCING STATES[c]

Year State	1972	1973	1974[b]
	1,000 Acres		
Iowa	10,600	11,150	11,750
Illinois	9,225	9,670	10,150
Indiana	4,884	5,240	5,500
Ohio	3,090	3,040	3,700
Missouri	2,500	2,600	2,750
Subtotal, Corn Belt	30,299	31,700	33,850
Minnesota	4,899	5,520	5,810
Nebraska	5,135	5,850	5,000
South Dakota	2,414	2,630	2,300
Wisconsin	2,143	2,090	2,090
Georgia	1,490	1,670	1,800
Michigan	1,722	1,690	1,730
North Carolina	1,280	1,400	1,570
Kansas	1,250	1,540	1,400
Kentucky	968	1,010	1,120
Pennsylvania	900	1,040	1,070
Subtotal, major producing states outside Corn Belt	22,201	24,440	23,890
All other states	4,921	5,620	6,006
United States	57,421	61,760	63,746

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[a] Corn for grain.

[b] Preliminary.

[c] Corn belt states; all other states growing more than 1 million acres, in decreasing order of number of acres grown in 1974.

Source: U.S. Department of Agriculture (1974c).

QUANTITIES OF PESTICIDES USED ON CORN

The U.S. Department of Agriculture (1974b) conducted a survey on the agricultural uses of pesticides in 1971 (Tables 4 to 7). The Department reports that corn led all other crops by a wide margin in the total volume of herbicides used. American farmers used 101.1 million pounds of herbicides (active ingredient) on corn, that is 45% of the total quantity of herbicides used on agricultural crops in 1971. Corn was second in volume of insecticides used (preceded by cotton); farmers used 25.5 million pounds of insecticide active ingredients on corn in 1971, that is 17% of the total quantity of insecticides used on crops that year. The quantities of fungicides used on corn are so small that they were not disaggregated in the USDA pesticide use report for 1971 (or for 1966). Some miticides (57,000 lb) and fumigants (386,000 lb) were also used on corn in 1971, according to the USDA survey.

Table 4 provides a breakdown of the pesticides used on corn in 1971 by type of pesticide and by farm production regions, following the U.S. Department of Agriculture's division of the United States into 10 regions as shown in Figure 2. In line with the concentration of the production of corn in the Corn Belt, Lake, and Northern Plains States, these three regions accounted for the lion's share of all herbicides, insecticides, and "miscellaneous pesticides" used on corn in 1971. As Table 4 shows in detail, these three regions used 85% of all herbicides, 94% of all insecticides, 87% of all miscellaneous pesticides, and 87% of all pesticides used on corn in 1971, according to the USDA report.

The use of herbicides, insecticides, and miscellaneous pesticides on corn in 1971 by major products and by regions is further detailed in Tables 5, 6, and 7. These use patterns will be examined in greater detail below, in the sections dealing with corn herbicides and insecticides, respectively.

Table 8 presents a comparison of the quantities of pesticides used on corn in the United States in 1964, 1966, and 1971, according to the USDA pesticide use surveys for these years (U.S. Department of Agriculture, 1968, 1970, 1974b). The total quantity of all pesticides used on corn increased from 41.8 million pounds in 1964 to 70.1 million pounds in 1966, and further to 127.0 million pounds in 1971, a more than three-fold increase from 1964 to 1971. The use of corn herbicides increased almost four-fold from 25.5 million pounds in 1964 to 101.1 million pounds in 1971. The quantity of insecticides used on corn increased from 15.7 million pounds in 1964 to 23.6 million pounds in 1966, and to 25.5 million pounds in 1971, an increase of 63% from 1964 to 1971.

Table 4. PESTICIDE USAGE ON U.S. CORN CROP IN 1971 BY REGION

Region	Herbicides		Insecticides		Miscellaneous pesticides		Total pesticides[a]	
	1,000 lb	%	1,000 lb	%	1,000 lb	%	1,000 lb	%
Northeast	5,250	5.2	155	0.6	1	0.2	5,406	4.3
Lake States	21,358	21.1	2,749	10.8	-	-	24,107	19.0
Corn Belt	54,069	53.5	15,314	60.0	-	-	69,383	54.6
Northern Plains	10,700	10.6	5,852	22.9	386	87.1	16,938	13.3
Appalachian	6,166	6.1	375	1.5	-	-	6,541	5.1
Southeast	2,105	2.1	42	0.2	-	-	2,147	1.7
Delta States	474	0.5	37	0.1	-	-	511	0.4
Southern Plains	127	0.1	54	0.2	-	-	181	0.1
Mountain	566	0.6	928	3.6	-	-	1,494	1.2
Pacific	245	0.2	25	0.1	56	12.7	326	0.3
Total	101,060	100.0	25,531	100.0	443	100.0	127,034	100.0

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[a] Fungicides used on corn are not listed separately in the USDA report. Fungicides are not included in the pesticide total in this table.

Source: "Farmers' Use of Pesticides in 1971 - Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

Table 5. HERBICIDES USED ON CORN, BY REGION, 1971[a/]
(1,000 lb)

	Regions										
Herbicide	North-east	Lake States	Corn Belt	Northern Plains	Appalachian	South-east	Delta States	Southern Plains	Mountain	Pacific	Total
Atrazine	3,600	13,000	23,600	6,300	4,500	350	300	50	250	50	52,000
Propachlor	85	5,250	13,900	2,000	5	-	40	10	-	10	21,300
2,4-D	350	1,250	4,800	1,500	750	200	60	9	200	25	9,144
Alachlor	850	1,000	5,900	100	400	50	20	20	20	-	8,360
Butylate	120	160	3,800	150	195	1,250	-	-	43	100	5,818
Simazine	110	120	500	-	120	50	-	-	-	20	920
Linuron	10	30	600	100	10	5	20	5	20	4	804
Propazine	-	-	190	170	21	185	2	13	-	2	583
EPTC	10	100	50	100	-	10	-	2	10	10	292
Dicamba	3	50	150	60	-	-	-	1	10	10	284
MCPA	2	75	4	75	-	-	-	-	-	3	159
Others	110	323	575	145	165	5	32	17	13	11	1,396
Total	5,250	21,358	54,069	10,700	6,166	2,105	474	127	566	245	101,060

Source: "Farmers' Use of Pesticides in 1971 - Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

[a/] Use of each individual insecticide, by region, is an MRI estimate.

Table 6. INSECTICIDES USED ON CORN, BY REGION, 1971[a,b]
(1,000 lb)

	Regions										
Insecticide	North-east	Lake States	Corn Belt	Northern Plains	Appalachian	South-east	Delta States	Southern Plains	Mountain	Pacific	Total
Aldrin	-	90	7,350	235	40	20	10	1	10	3	7,759
Bux	5	810	1,370	1,360	-	-	-	30	-	-	3,575
Carbofuran	50	790	1,140	630	20	4	12	-	30	5	2,681
Phorate	2	200	1,700	400	50	1	1	5	300	2	2,661
Diazinon	5	300	800	780	20	1	-	-	80	5	1,991
Carbaryl	20	100	400	1,000	100	2	1	5	20	1	1,649
Parathion	5	50	40	900	25	2	-	5	300	2	1,329
Heptachlor	4	10	1,090	-	-	-	-	-	-	-	1,104
Chlordane	35	200	560	-	30	4	-	3	8	2	842
Disulfoton	8	30	20	120	30	-	-	2	100	2	312
Others	21	169	844	427	60	8	13	3	80	3	1,628
Total	155	2,749	15,314	5,852	375	42	37	54	928	25	25,531

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a/ Figures for total use of each insecticide and regional totals were obtained from "Farmers' Use of Pesticides in 1971 - Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

b/ Use of each individual insecticide, by region, is an MRI estimate.

Table 7. MISCELLANEOUS PESTICIDES USED ON CORN, BY REGION, 1971[a,b]
(1,000 lb)

	Regions										
Pesticide	North-east	Lake States	Corn Belt	Northern Plains	Appalachian	South-east	Delta States	Southern Plains	Mountain	Pacific	Total
Dicofol	-	-	-	-	-	-	-	-	-	56	56
Other Miticides	1	-	-	-	-	-	-	-	-	-	1
Miscellaneous Fumigants	-	-	-	386	-	-	-	-	-	-	386
Total	1	0	0	386	0	0	0	0	0	0	443

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a/ Figures for total use of each pesticide and regional totals were obtained from "Farmers' Use of Pesticides in 1971 - Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

b/ Use of each individual pesticide, by region, is an MRI estimate.

Table 8. USE OF PESTICIDES ON CORN IN THE U.S. IN 1964, 1966, AND 1971

Type of pesticide	Year		
	1964	1966	1971
	(1,000 lb of active ingredient)		
Fungicides	543	N.A.	N.A.
Insecticides[a]	15,668	23,629	25,531
Herbicides[a]	25,476	45,970	101,060
Miscellaneous pesticides	76	546[b]	443[c]
All pesticides	41,773	70,145[d]	127,034[d]

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[a] Excluding petroleum.
[b] Includes 117,000 lb miticides, 429,000 lb fumigants.
[c] Includes 57,000 lb miticides, 386,000 lb fumigants.
[d] Excluding fungicides.
N.A. = Not available
Sources: U.S. Department of Agriculture (1968, 1970, 1974b).

During the period 1964 to 1974, the total U.S. acreage of corn harvested for grain was as follows (U.S. Department of Agriculture 1973, 1974a):

Year	1,000 acres
1964	55,369
1965	55,392
1966	57,002
1967	60,694
1968	55,980
1969	54,574
1970	57,358
1971	64,047
1972	57,421
1973	61,760
1974 (Preliminary)	63,746

These data show that the corn acreage in the United States increased by less than 3% from 1964 to 1966, while the use of insecticides increased by 51% (from 15.7 to 23.6 million pounds of active ingredient), and the use of herbicides by 80% (from 25.5 to 46 million pounds of active ingredient). The further increase in the use of herbicides on corn from 1966 to 1971 is equally striking. While the acreage of corn harvested for grain increased by 12% from 1966 to 1971, the use of herbicides increased by 120% (from 46 million pounds in 1966 to 101.1 million pounds of active ingredient in 1971). These data document that the increases in the quantities of pesticides, especially of herbicides, used on corn are primarily due to higher average inputs per acre, and only to a small extent to an increase in corn acreage.

The USDA pesticide use surveys as well as Cooperative Extension Service publications and state pesticide use surveys indicate that the use of pesticides other than herbicides and insecticides on corn is very small or negligible.

The data presented in this section and those on the geographic distribution of corn presented in the preceding section indicate that our study on the efficiency of current pesticide use practices on corn should be focused on the use of herbicides and insecticides on corn in the Midwest.

HERBICIDE USE PRACTICES

The rate of use of herbicides on corn in the United States has increased greatly from 1964 to 1971, as summarized above. In 1964, 25.5 million pounds of herbicide active ingredients were applied to corn, 46.0 million pounds in 1966, and 101.1 million pounds in 1971 (Table 8). Thus, the quantities of herbicides used on corn almost quadrupled from 1964 to 1971, while the corn acreage harvested for grain increased by only 16% during this period.

The U.S. Department of Agriculture (1972) conducted surveys on the use of herbicides on agricultural crops in 1959, 1962, 1965, and 1968. Table 9 presents the results of these surveys for corn. During the 10 year time span covered, the corn acreage receiving herbicide treatments increased from 20 million acres in 1959 to 48.9 million acres in 1968. The percentage of the total corn acreage treated with herbicides increased from 25% in 1959 to 39% in 1962, 68% in 1965, and 76% in 1968. Of the 48.9 million acres of corn treated with herbicides in 1968 according to this survey, 20.4 million acres were treated preemergence only (at an average cost of $4.84/acre); 18.9 million acres were treated postemergence only ($2.46/acre); and 9.6 million acres were treated both pre- and postemergence ($6.15/acre).

Table 9. ESTIMATED EXTENT OF CHEMICAL WEED CONTROL ON CORN IN THE U.S., 1959 TO 1968

Year	1959	1962	1965	1968
Acreage treated with herbicides, 1,000 acres	20,051	25,302	45,012	48,930
Percent of total corn acres harvested for grain	25%	39%	68%	76%

Source: U.S. Department of Agriculture (1972).

More recent data on the extent of use of herbicides on corn in the Midwest were reported by von Rümker and Horay (1974). Of about 300 corn growers in Iowa and Illinois who responded to detailed questions regarding their pesticide use practices, all but two reported using corn herbicides in 1973. About 85% of the respondents from both states believed that all of their corn acres need herbicide treatments each year. Based on these farmer responses, on the findings of other recent pesticide use surveys, and on information from midwestern weed research and extension workers, vom Rümker and Horay (1974) concluded that herbicides are used by close to 100% of all corn growers in the leading midwestern corn-producing states, and that close to 90% of the total corn acreage in the region is treated with herbicides. Since a substantial percentage of the total corn acreage receives both pre- and postemergence treatments, the total number of "gross" acres treated (acres treated more than once counted for each treatment) exceeds the total corn acreage harvested for grain.

Table 5 presents a breakdown of the herbicides used on corn in 1971 by regions and by major individual herbicides. Of the total quantity of herbicides used on corn in 1971 according to the U.S. Department of Agriculture (1974b), about 54% (54.0 million pounds) were used in the five Corn Belt States, and 85% of the total (86.1 million pounds) in the Lake, Corn Belt, and Northern Plains States combined. Much smaller quantities of herbicides were used on corn in all other regions.

One single product, atrazine, accounted for more than 50% of the total quantity of herbicides used on corn, according to the USDA survey. In decreasing order of use volume, atrazine was followed by propachlor (21.3 million pounds), 2,4-D (9.1 million pounds), alachlor (8.4 million pounds), and butylate (5.8 million pounds). All other corn herbicides were used in 1971 in quantities less than 1 million pounds, according to this source.

Herbicides are used on corn for the control of a variety of weeds including pigweeds, crabgrasses, lambsquarters, quackgrass, foxtails, nutsedges, Canada thistle, johnsongrass, barnyard grass, bindweeds, cocklebururs, morning glories, panicums, kochia, velvetleaf, and witchgrass. Of the 48 states that participated in the corn phase of the 1968 herbicide use survey by the U.S. Department of Agriculture (1972), 42 states reported an upward trend in herbicide use, six reported a stationary situation, while nine reported a downward trend.

Extension weed scientists and agronomists contacted in the present study reported that 90 to 95% of the corn acres in their respective states were treated at least once with a herbicide, and that at least that many or more corn acres needed the herbicide treatment.

The costs of chemical weed control in corn per acre have increased substantially during the last 10 to 15 years. Increased costs per pound of the herbicides have contributed to this increase only to a minor extent. The major part of the cost increase per acre is due to the fact that weed species that are more difficult to control are gradually becoming more predominant in corn fields, as those species that are easily controlled recede. As a result, herbicide application rates per acre were increased, relatively inexpensive herbicides like 2,4-D were replaced by more expensive preemergence herbicides, postemergence treatments were added to preemergence treatments, and single herbicides are being replaced by combinations of two products. The question how fast this trend will further progress, and what its economic and ecological end point might be apparently has not received much, if any study thus far.

The economic part of the question is not pressing as long as the farm value of the crop increases more rapidly than the cost of using herbicides, as has been the case in recent years (Table 2). Nevertheless, the cost of chemical weed control in corn ($6.00 to $15.00/acre and up for preemergence herbicides) represents a significant fraction of the corn production costs and of the farm value of the crop, providing an economic incentive for corn growers to use herbicides efficiently and at minimum effective rates.

In addition, many herbicides have a limited safety margin between the rate that will kill weeds and the rate that may injure the crop. This is another incentive for growers not to use herbicides at rates higher than necessary.

Several of the U.S. Department of Agriculture/State Cooperative Pilot Pest Management Projects on corn initiated in 1973 include weed phases (Illinois, Indiana, Iowa, Nebraska, and Ohio). Pest management programs for weeds seem to tend in the direction of total farm weed control. For instance, Illinois' summary on its corn pest management project for 1973 states: "More emphasis is needed on weed control in forage crops, small grains, and noncropland along with control programs in corn and soybeans if the weed seed population in the soil is going to be reduced and progress in weed management is to be achieved." This "total farm weed control" concept recently received support from Rodgers (1974), then the President of the Weed Science Society of America, and from other prominent weed scientists.

This approach may require more extensive use of chemical herbicides (and of other weed control measures) at least until the weed seed reservoir in the soil is depleted. No data appear to be available on how many years this may take under field conditions, whether benefits will outweigh costs, and how the desired area-wide simplification of agro-ecosystems might affect other components of the system, such as the soil microflora and fauna, and desirable animal species such as certain birds, game, beneficial insects, and others.

In summary, practically all corn growers and weed research and extension workers believe that chemical herbicides are essential to the efficient and profitable production of corn, that the quantities of herbicides used on corn are needed, and that corn herbicides are used efficiently. Herbicide costs and the possibility of crop injury from overapplication provide practical incentives against unnecessary or wasteful use of corn herbicides. We found no research data to show whether economic weed control could be achieved by substantially reduced rates of chemical herbicides or by other means.

The "total farm weed control" concept promoted in some pest management programs for weeds will require heavier, rather than reduced herbicide inputs at least in the initial weed eradication phase.

INSECTICIDE USE PRACTICES

As documented above in the section "Quantities of Pesticides Used on Corn," the use of insecticides on corn increased by 63% from 1964 to 1971, namely, from 15.7 million pounds of active ingredients in 1964 to 25.5 million pounds in 1971, according to the pesticide use surveys by the U.S. Department of Agriculture (1968, 1970, 1974b). During the same time span, the U.S. acreage of corn harvested for grain increased by only 15.7%. These data indicate that insecticide inputs per acre of corn increased considerably during this 8-year period.

According to the 1971 USDA pesticide use survey, a total of 25.5 million pounds of insecticide active ingredients were used on corn that year (Table 6). Of this total, 9.7 million pounds consisted of chlorinated hydrocarbon insecticides (aldrin, heptachlor, and chlordane); the balance was made up of four organic phosphate and three carbamate insecticides; and other insecticides that were not disaggregated.

Other recent studies indicate that the U.S. Department of Agriculture's estimates on the quantities of insecticides used on corn in 1971 are probably too low. For example, von Rümker and Horay (1974) estimated that 18.5 million pounds of insecticides were used on corn in 1971 in Iowa and Illinois alone, that is 3.2 million pounds in excess of the USDA estimate for the entire Corn Belt (Table 6). In 1971, Iowa and Illinois raised 64% (21.8 million acres) of all corn acres in the Corn Belt (33.9 million acres).

Furthermore, the use of aldrin on corn in 1971 was estimated to be 7.8 million pounds by USDA (U.S. Department of Agriculture, 1974b), but an estimate of 9.4 million pounds for this use was provided by EPA in the recent aldrin/dieldrin cancellation proceedings (Train, 1974). This latter estimate appears to be more authoritative and in better agreement with other information cited above.

In the midwestern corn-growing states, corn may be attacked by a number of soil and foliar insects. Overall, the soil insects are of much greater economic importance than those feeding above ground.

Corn soil insects include three species of corn rootworms, and a number of other insects often referred to as the "soil insect complex." The corn rootworm species occurring in the Midwest are *Diabrotica longicornis*, the northern corn rootworm; *D. virgifera*, the western corn rootworm; and *D. undecimpuncata howardi*, the southern corn rootworm. The northern and western species predominate in Iowa and Illinois. They often occur together and have similar life cycles and habits. Western corn rootworms are completely, and northern rootworms almost completely resistant to chlorinated hydrocarbon insecticides in the principal midwestern corn-producing states. Corn rootworms are usually a problem only on corn following corn, sorghum, or sunflowers. Corn following soybeans or small grains rarely suffers rootworm damage.

The "corn soil insect complex" includes seedcorn maggots, *Hylemya* spp.; the seedcorn beetle, *Agonoderus lecontei*; the slender seedcorn beetle, *Clivina impressifrons*; wireworms (order *Coleoptera*, family *Elateridae*); cutworms (order *Lepidoptera*, family *Noctuidae*); white grubs, *Phyllophaga* or *Lachnosterna* spp.; webworms, *Crambus* spp.; billbugs, *Calendra* spp.; ants (order *Hymenoptera*, family *Formicidae*); and the corn root aphid, *Anuraphis maidiradicis*. These soil insects are most serious on first year corn following legumes, legume grass or grass sods. They are seldom a problem on corn following corn or soybeans in the rotation.

Foliar insects that may attack corn in the Midwest include corn borers (order Lepidoptera, family Pyralididae); the corn earworm, Heliothis zea; corn rootworm beetles, the adult forms of the corn rootworms (Diabrotica spp.) discussed above, the corn leaf aphid, Rhopalosiphum maidis; the corn flea beetle, Chaetocnema pulicaria; the armyworm, Pseudaletia unipuncta; the fall armyworm, Spodoptera frugiperda; and grasshoppers (order Orthoptera, family Locustidae).

Table 10 presents an overview of the insecticides that were recommended against the major corn soil insects in 1974 by extension entomologists in eight midwestern states, detailed by states, insecticides, rates, and target insects. Seven of the eight midwestern states did not recommend any chlorinated hydrocarbon insecticides against corn rootworms, the only exception being Indiana which still recommended aldrin and heptachlor against these insects. Against wireworms and white grubs, aldrin, chlordane and/or heptachlor were recommended in seven of the eight midwestern states; Illinois did not recommend any chlorinated hydrocarbon insecticides against these insects. Against cutworms, aldrin, heptachlor and/or chlordane were recommended in five of the eight midwestern states. Alternative cutworm control recommendations in Illinois, Minnesota, and Nebraska included carbaryl, trichlorfon, diazinon, and/or toxaphene. Against seed beetles and maggots, aldrin and heptachlor seed treatments were recommended in five of the states, while Iowa, Illinois, and Ohio recommended only diazinon seed treatments.

Entomologists at the University of Illinois have studied corn insect infestations, and the effectiveness of insecticides in averting yield losses due to these insects since 1955 (Petty, 1974; Kuhlman et al. 1973, Randell et al. 1974; Wedberg et al. 1975). Estimates on the extent and profitability of the use of insecticides on corn in Illinois in 1972, 1973, and 1974 according to these authors are summarized in Table 11. These estimates indicate that Illinois corn growers realized net returns from the use of insecticides on corn of $22.8 million ($3.55/acre treated) in 1972, $22.2 million ($3.55/acre) in 1973, and $30.7 million ($4.62/acre) in 1974. In each of the 3 years, more than 90% of the total estimated profits resulted from the use of insecticides against soil insects, based on yield increases from use of corn rootworm insecticides. Thus, on the surface, the use of corn soil insecticides appears to be a profitable practice. However, the estimated profits per acre in Table 11 are averages which,

Table 10. INSECTICIDES RECOMMENDED AGAINST CORN SOIL INSECTS IN 1974 BY EXTENSION ENTOMOLOGISTS IN EIGHT MIDWESTERN STATES

State	Target insects: Corn rootworms	Target insects: Wireworms and white grubs	Target insects: Cutworms	Target insects: Seed beetles and maggots
	(Lb of active ingredient per acre)			
Iowa	Carbofuran 0.75-1.0 Dasanit® 1.0 Dyfonate® 1.0 Landrin® 1.0 Mocap® 1.0 Phorate 1.0	Aldrin 1.0 Chlordane 2.0 Carbofuran 0.75-1.0 Heptachlor 1.0 Phorate 1.0	Aldrin 1.0-2.0 Chlordane 2.0-4.0 Heptachlor 1.0-2.0 Carbaryl bait 1.0 Carbaryl spray 2.0 Toxaphene 2.0 Trichlorfon 1.0	Diazinon seed treatment
Illinois	Carbofuran 0.75-1.0 Dasanit® 1.0 Dyfonate® 1.0 Landrin® 1.0 Phorate 1.0	Carbofuran 2.0 Diazinon 1.5	Carbaryl bait 1.0 Carbaryl spray 2.0 Trichlorfon 1.0	Diazinon seed treatment
Indiana	Carbofuran 0.75 Dyfonate® 1.0 Phorate 1.0 Dasanit® 1.0 Bux® 1.0 Mocap® 1.0 Aldrin 1.0 Heptachlor 1.0 Diazinon 1.0	Aldrin 3.0 Heptachlor 3.0 Diazinon 4.0 Dyfonate® 4.0 Mocap® 2.0 Carbofuran 2.0 Phorate 1.0	Adlrin 3.0 Heptachlor 3.0 Diazinon 4.0 Carbaryl spray or bait Trichlorfon spray or bait Toxaphene 2.0	Aldrin Diazinon Heptachlor Lindane Seed treatment
Ohio	Carbofuran 1.0 Dasanit® 0.75-1.0 Dyfonate® 0.75-1.0 Phorate 1.0	Aldrin 2.0 Heptachlor 2.0	Carbaryl bait 1.0 Carbaryl spray 2.0 Chlordane 4.0 Heptachlor 2.0 Toxaphene 2.0 Trichlorfon 1.0	Diazinon seed treatment
Missouri	Bux® 1.0 Carbofuran 0.75-1.0 Dasanit® 1.0 Diazinon 1.0 Phorate 0.75-1.0	Aldrin 3.0-4.0 Diazinon 3.0-4.0 Dyfonate® 4.0 Heptachlor 3.0-4.0	Aldrin 1.5-2.0 Carbaryl 1.0-2.0 Diazinon 3.0-4.0 Heptachlor 1.5-2.0 Toxaphene 2.0-3.0 Trichlorfon 1.0	Aldrin Diazinon Dieldrin Heptachlor Lindane Seed treatment
Minnesota	Carbofuran 1.0 Dasanit® 1.0 Diazinon 1.0 Dyfonate® 1.0 Phorate 1.0	Aldrin 2.0 Chlordane 4.0 Diazinon 1.0-2.0 Dyfonate® 1.0 Heptachlor 2.0 Phorate 1.0	Carbaryl 2.0 Toxaphene 2.0 Trichlorfon 1.5	Aldrin Diazinon Dieldrin Heptachlor Seed treatment
South Dakota	Carbofuran 1.0 Dasanit® 1.0 Dyfonate® 1.0 Mocap® 1.0 Phorate 1.0	Aldrin 2.0 Chlordane 4.0 Heptachlor 2.0	Aldrin 2.0 Carbaryl bait 1.0 Carbaryl spray 2.0 Diazinon 2.0 Heptachlor 2.0 Toxaphene 2.0 Trichlorfon 1.0	Aldrin Heptachlor Lindane Diazinon Seed treatment
Nebraska	Bu ® 1.0 Carbofuran 1.0 Dasanit® 1.0 Dyfonate® 1.0 Disyston® 1.0 Mocap® 1.0 Phorate 1.0	Aldrin 2.0 Chlordane 4.0 Heptachlor 2.0	Carbaryl 1.0 Diazinon 4.0	Aldrin Diazinon Dieldrin Heptachlor Lindane Seed treatment

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Source: von Rümker et al. (1975).

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Table 11. EXTENT AND PROFITABILITY OF THE USE OF INSECTICIDES ON CORN IN ILLINOIS, 1972-1974

	Target insects[a]	Acres treated	Estimated profit[b] Total	Estimated profit[b] Per acre
1972	Soil insects	6,085,328	$21,298,648[c]	$3.50[c]
	Cutworms	124,430	746,580	6.00
	European corn borer	69,944	104,916	1.50
	Corn leaf aphid	55,669	389,683	7.00
	Grasshoppers	51,882	51,882	1.00
	Corn rootworm adults	36,002	144,008	4.00
	Armyworm	24,695	37,043	1.50
	Fall armyworm	4,609	11,523	2.50
	Total	6,452,559	22,784,283	3.53
1973	Soil insects	5,738,053	$20,083,186[c]	$3.50[c]
	Corn leaf aphid	137,292	961,044	7.00
	Fall armyworm	124,063	310,158	2.50
	European corn borer	108,284	162,426	1.50
	Cutworms	93,781	562,686	6.00
	Corn rootworm adults	24,642	98,568	4.00
	Armyworm	19,593	29,390	1.50
	Total	6,258,537	22,220,287	3.55
1974	Soil insects	6,014,342	$28,175,647[c]	$4.68[c]
	Corn leaf aphid	201,032	1,409,114	7.01
	European corn borer	126,943	253,886	2.00
	Fall armyworm	113,980	284,950	2.50
	Corn flea beetle	84,314	126,471	1.50
	Cutworms	56,756	340,536	6.00
	Corn rootworm adults	29,980	119,920	4.00
	Armyworm	13,179	19,769	1.50
	Grasshoppers	10,891	16,337	1.50
	Total	6,651,417	30,746,630	4.62

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[a] Listed in decreasing order of number of acres treated each year.

[b] Over and above treatment costs.

[c] Based on yield increase from use of corn rootworm insecticides.

Source: Adapted from Kuhlman et al. (1973), Randell et al.(1974), and Wedberg et al. (1975).

as further analysis reveals, consist of much higher net returns from the use of insecticides on corn acres that actually needed the treatment, and minimal or no returns from acres treated unnecessarily.

Table 12 presents an estimate on the use and profitability of soil insecticides for corn rootworm control in Illinois for the 11-year period, 1964 to 1974. The assumptions used by the Illinois authors in calculating these data as summarized in the lower part of the table are very interesting. They are based on reports from county extension advisors and on research and field demonstration studies by Illinois entomologists. According to these sources, only about 40 to 50% of all corn acres treated with soil insecticides during the last 4 years needed the treatment, that is only about 20% of all corn acres harvested for grain in Illinois during that period. The yield loss prevented by the use of insecticides on acres needing the treatment averaged 10.0 bu/acre from 1971 to 1973, and was estimated at 6.2 bu/acre in 1974. The farm price of corn used in the estimate was $1.00/bu for 1971 to 1973, $2.75/bu for 1974. Thus the estimated value of the yield loss prevented on the acres needing the treatment was $7.00/acre for 1971 to 1973, $13.65/acre in 1974. Furthermore, it was estimated that on the acres treated unnecessarily (60% of all treated acres 1971 to 1973, 50% of all treated acres in 1974), growers realized a net return above the cost of the treatment of $1.00/acre in 1971 to 1973, and zero in 1974.

The average net gain for all acres treated, $3.50/acre for the period 1971 to 1973, was calculated as follows: of 6 million acres of corn treated with soil insecticides, only 2.5 million acres = 41-2/3% needed the treatment, returning $7.00/acre net. On the balance of the treated acreage, 3.5 million acres = 58-1/3% of the total treated acreage, net returns from the treatment averaged only $1.00/acre above the cost of treatment. The average net gain for all acres treated, therefore, was:

41.667 x $7.00 $291.67

58.333 x $1.00 58.33

$350.00 : 100 $3.50/acre

The corresponding data for 1974 were computed in the same manner.

The higher average net returns from the use of corn soil insecticides in the earlier years (Table 12) are based on the fact that prior to 1971, corn rootworm populations were considerably higher and thus more damaging, so that the return from using a corn rootworm insecticide was greater. The corn rootworm problem has lessened during the last few years. The re-increase in the average profit per acre in 1974 is due to the increase in the price of corn and thus in the value of the yield loss prevented, rather than to a rebound of corn rootworm damage.

Table 12. ESTIMATED USE AND PROFITABILITY OF SOIL INSECTICIDES FOR CORN ROOTWORM CONTROL IN ILLINOIS, 1964-1974

Year	Corn acres treated with soil insecticides	Average profit[a] ($/acre)	Total profit ($)
1964	4,091,125	4.00	16,364,500
1965	4,733,784	5.00	23,668,920
1966	5,443,197	5.00	27,215,985
1967	6,204,293	5.00	31,021,465
1968	6,261,869	5.00	31,309,345
1969	6,508,067	5.00	32,540,335
1970	6,610,287	3.75	24,788,576
1971	6,142,039	3.50[b]	21,497,137
1972	6,085,328	3.50	21,298,648
1973	5,738,053	3.50	20,083,186
1974	6,014,342	4.68[c]	28,175,647

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a/ Assumptions:	1971-1973[b]	1974[c]
Cost of insecticide treatment/acre	$3.00	$3.40
Farm price of corn/bu	$1.00	$2.75
Acres needing treatment relative to		
-all corn acres treated	41-2/3%	50%
-all corn acres harvested for grain	20%	20%
On acres needing treatment		
-yield loss prevented/acre	10.0 bu	6.2 bu
-value of yield loss prevented/acre	$10.00	$17.05
-less cost of treatment/acre	$3.00	$3.40
-net return from treatment/acre	$7.00	$13.65
On acres not needing treatment net return above cost of treatment/acre	$1.00	None
Average net gain for all acres treated, per acre	$3.50	$4.68

Sources: Randell et al. (1974), Kuhlman (1973, 1975)

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The estimates on the economic benefits from the use of insecticides on corn in Illinois discussed above are presented and quoted as given in the sources cited, in contemporary dollars. One might question if estimates of this type should not be given in more rounded, less specific terms, or if dollar figures should be price-adjusted. However, these Illinois data are derived from an ongoing study. They are updated annually, and they are widely accepted and used by entomologists, extension personnel and others in their present form. Therefore, it seemed preferable to present and discuss them in their original, unaltered form in this report.

A breakdown of the types of corn soil insecticides used in Illinois during the same 11-year period, 1964 to 1974, is given in Table 13. In the early days of the use of soil insecticides on corn, chlorinated hydrocarbon insecticides (primarily aldrin) controlled both corn rootworms and the complex of other soil insects. Today, as pointed out above, western and northern corn rootworms are highly resistant to chlorinated hydrocarbon insecticides in many areas. In recent years, organic phosphate and carbamate insecticides have been used primarily against resistant rootworms, and chlorinated hydrocarbons against the other corn soil insects.

The data summarized in Table 13 show that the total corn acreage treated with soil insecticides in Illinois has remained almost level from about 1967 to the present, except for relatively small year-to-year oscillations. The acreage treated with chlorinated hydrocarbon insecticides decreased from 4.0 million acres (98% of all acres treated) in 1964 to 1.9 million acres (31% of all acres treated) in 1974.

Shaw et al. (1975) describe two methods for predicting damage from corn rootworms, i.e., (a) counting adult rootworms per plant on two different dates in August, and (b) counting corn rootworm eggs in soil samples taken in the field in the fall. If one or more adult corn rootworms per plant are found on either count in August, a soil insecticide should be used if the field is again planted to corn the next year. All corn fields with 5 million or more corn rootworm eggs per acre should be treated with a soil insecticide the following year. Careful examinations of rootworm damage and yield loss in corn fields in 1974 showed that there was no damage at 1 million eggs per acre, only slight damage at 9 million eggs per acre, moderate damage at 13 million eggs per acre, and severe damage at 18 million eggs per acre. Thus, the suggestion to treat when there are 5 million or more eggs per acre is conservative.

Table 13. USE OF CORN SOIL INSECTICIDES IN ILLINOIS, 1964 TO 1974

Year	Acres treated with		Total acres treated
	Chlorinated hydrocarbons	Organic phosphates and carbamates	
1964	4,009,303	81,822	4,091,125
1965	4,544,432	189,352	4,733,784
1966	5,116,605	326,592	5,443,197
1967	5,601,572	602,721	6,204,293
1968	5,170,726	1,091,143	6,261,869
1969	4,517,931	1,990,138	6,508,069
1970	3,844,740	2,765,547	6,610,287
1971	2,723,119	3,418,920	6,142,039
1972	1,933,089	3,852,239	5,785,328[a]
1973	1,737,510	3,960,543	5,698,053[a]
1974	1,886,042	4,128,300	6,014,342

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[a] These figures vary slightly from those reported in Table 11 for reasons not known, but the variations are not large enough to be of significance to the objectives of this study.

Source: Adapted from Kuhlman et al. (1973), Wedberg et al. (1975).

Field observations in 1973 and 1974 by these authors indicate that over one-half of the corn fields in Illinois have rootworm counts of less than 5 million eggs per acre.

Shaw et al. (1975) also studied wireworm damage to corn. By using a bait method as a diagnostic tool, 21 corn fields were examined in 1974. Wireworm larvae were found in only two of the 21 fields baited. One of these had only one larvae on the six baits placed in each field, that is considerably below the suggested treatment threshold of four or more larvae per six baits. The second field had a total of 41 larvae on the six baits, and use of a soil insecticide was recommended in this case. The survey indicates that only a small percentage of all corn fields in Illinois require the use of insecticides against wireworms.

In May and June of 1974, Shaw et al. (1975) investigated many reports of black cutworm (*Agrotis ypsilon*) damage in corn received from farm advisers in west-central and southern Illinois. From these reports, 15 fields in 10 different counties were selected for observation. For each field, information was obtained on the 1973 crop preceding corn in the rotation, tillage practices, field drainage, percent cutworm damage in the highest damage area within each field, and cutworm control measures taken. Characteristics that appeared to be common to fields with a black cutworm problem included the following:

* Cutworm problems in previous years (11 of 15 fields).

* Considerable surface debris and litter from no-till, minimum-till, or chisel plowing (14 of 15 fields).

* Soybeans preceded corn in the rotation (11 of 15 fields).

* Bottomland or low elevation location (13 of 15 fields).

* Poor drainage (14 of 15 fields).

The authors suggest that fields with all of these characteristics have a high potential for black cutworm infestation and damage. In greenhouse experiments, they tested the theory that a large number of black cutworm larvae could be killed with systemic insecticide placed in the seed furrow at planting time. A 10% granular formulation of carbofuran applied in this manner at the rate of 1 lb of active ingredient per acre killed 100% of small first and second instar larvae, and 60% of larger third, fourth, and fifth instar larvae within 48 hr after the larve were released on the treated plants. A band application of carbofuran at the same rate of active ingredient per acre was considerably less effective, particularly on the smaller larvae.

The data summarized in Table 11 show that an estimated 124,430 acres of corn were treated for cutworms in Illinois in 1972, 93,781 acres in 1973, and 56,756 acres in 1974. The net return estimates indicate that cutworm treatments were among the more profitable uses of corn insecticides.

The corn acreage treated for the control of all foliar insects of corn combined amounted to less than 10% of the acreage treated against soil insects in Illinois in each of the 3 years covered in Table 11. Among the foliar insects, control of the corn leaf aphid was considered to be relatively most profitable (net return $7.00/acre), followed by control of corn rootworm adults (net return $4.00/acre). Insecticides used against the remaining foliar insects of corn, i.e., the European corn borer, the corn flea beetle, grasshoppers, and armyworms yielded rather low economic benefits and accounted for only small percentages of the total corn acres treated with insecticides.

Comparable, detailed studies and historic data on the usefulness of insecticides on corn are, to the best of our knowledge, not currently available for any other corn-producing state. However, several other, although less detailed, estimates on the use of corn soil insecticides from other sources tend to support the findings of the Illinois entomologists. In 1973, von Rümker and Horay (1974) investigated the use patterns of corn insecticides in Iowa and Illinois in connection with a study on farmers' pesticide use decisions and attitudes on alternate crop protection methods. Responses from about 300 corn growers in Iowa and Illinois who were interviewed in this study indicated that 53% of the respondents in Iowa and 70% of those in Illinois used corn insecticides in 1973. Interestingly, only about one-half of the corn insecticide users, that is only about one-third of all corn growers interviewed, believed that all of their corn acres need insecticide treatments each year. Those growers who felt that not all of their corn fields needed insecticide treatments were then asked: "How do you decide which corn acres to treat and which not?" Responses to this question included the following:

* "Treat only corn on corn."
* "Treat only corn on sod."
* "Treat only corn on soybeans."
* "Treat only the seed."
* "Don't know how to tell if I need control chemicals, so I apply to all acres."

According to these authors (von Rümker and Horay, 1974), Iowa extension entomologists estimated that in 1973, about 5 million acres of corn in Iowa were treated with soil insecticides, 2.5 million of these (50%) with chlorinated hydrocarbons (aldrin 80%; heptachlor 16%; chlordane 4%). The entomologists felt that in 1973, chlorinated hydrocarbon insecticides (for the control of corn soil insects other than corn rootworms) were actually needed on about 1 million acres, that is about 40% of the acreage actually treated with these products.

In the present study, extension entomologists from four midwestern states provided the information on the number of corn acres treated with soil insecticides compared to acres needing treatment and to total corn acres in their respective states (Table 14). The responses from Illinois, Iowa and Indiana combined indicate that in those three states, about 54% (17.5 of 32.4 million acres) of the corn acreage harvested for grain received soil insecticide treatments. An estimated 45% of the treated acres needed the treatment, that is about 23% of the total acreage.

Table 14. CORN ACRES TREATED WITH SOIL INSECTICIDES IN SELECTED STATES COMPARED TO ACRES NEEDING TREATMENT AND ACRES HARVESTED FOR GRAIN, 1974

State	Acres harvested for grain	Acres treated with soil insecticides	Acres needing treatment	Acres needing treatment as percent of	
				Acres treated	Acres harvested
		(1,000 Acres)			
Illinois	10,150	6,000	2,000	33%	20%
Iowa	11,750	5,250	4,000	76%	34%
Indiana	5,500	2,600	300	12%	5%
Nebraska	5,000	3,690	N.a.	N.a.	N.a.
Totals	32,400	17,540			
-excl. Nebraska	27,400	13,850	6,300	45%	23%

Sources: Wedberg et al. (1975); Kuhlman (1975); Extension Entomologists in Iowa, Indiana and Nebraska (1975)

N.a. = Not available.

The data presented in this section suggest that substantial quantities of the insecticides used on corn for the control of corn rootworms and other soil insects are applied needlessly. Based on the thorough studies conducted in Illinois and the data from several other states discussed above, especially those summarized in Table 14, we estimate that about 50% of the quantities of soil insecticides that were used on corn during the last few years could be saved. In terms of the total quantity of insecticides that were used on corn in 1971 according to the USDA Pesticide Survey, 25.5 million pounds of active ingredients (Table 4), such savings would amount to about 12.8 million pounds.

Important prerequisites to improving the efficiency in the use of corn soil insecticides by avoiding unnecessary treatments include development and implementation of practical methods for diagnosing corn soil insect problems, and for predicting treatment needs. The progress reported in this regard by Shaw et al. (1975) is indeed encouraging.

As long as the average cost of applying a soil insecticide to an acre of corn is not much higher than the farm price per bushel of corn, there is no great economic incentive for corn growers to avoid unnecessary corn insecticide applications. However, this situation may change in the event that the relatively inexpensive chlorinated hydrocarbon insecticides would no longer be available. For instance, the grower cost of aldrin 20% granules at 1.5 lb of active ingredient per acre is about $2.20/acre, while carbofuran granules at 1.0 lb of active ingredient per acre will cost about $7.50/acre in 1975, according to pesticide trade sources. Against wireworms and white grubs, carbofuran may have to be used at up to 2.0 lb of active ingredient per acre, which would cost the grower $15.00/acre. Thus, while there has not been a strong economic incentive against wasteful use of corn soil insecticides in the past, this situation may change in the future.

SUMMARY

Corn, the leading agricultural crop in the United States by acreage as well as by farm value, is produced primarily in 11 midwestern states including the five "Corn Belt States," i.e., Iowa, Illinois, Indiana, Ohio, and Missouri. Fungicides and "miscellaneous pesticides" including miticides, fumigants, defoliants, desiccants, plant growth regulators and others are used on corn either in very small quantities or not at all and were therefore not studied in detail in this project.

The quantities of herbicides used on corn in the U.S. quadrupled from 1964 to 1971. More than 100 million pounds of herbicide active ingredients were used on corn in 1971, according to a report by the U.S. Department of Agriculture. It is estimated that close to 90% of the total U.S. corn acreage harvested for grain is treated with chemical herbicides at present. A significant fraction of this acreage receives more than one herbicide treatment. Weed research and extension specialists and corn growers are convinced that chemical herbicides are essential to the efficient, profitable production of corn, and that by and large, corn herbicides are used effectively and without waste.

The costs of chemical weed control per acre of corn have increased substantially during the last 10 years and continue to rise. In large part, this increase is due to a gradual change in corn weed populations. Weeds that are more difficult to control are becoming more prevalent as those species that are easily controlled recede. However, the farm value of corn has also increased substantially. Consequently, there do not appear to be significant economic constraints on corn growers' herbicide use practices.

Pest management programs for weeds are included in several of the corn pilot pest management programs that were initiated in 1973. The "total farm weed control" concept is being considered in some of these programs. This approach will require increased use of chemical herbicides (and of other weed control measures) at least during the weed eradication phase. Minimum and no-tillage practices are also likely to require increased chemical herbicide inputs. We found no data from any of these studies demonstrating or suggesting that economic weed control could be obtained by substantially lower herbicide inputs, or by other means.

Thus, there do not seem to be any near-term prospects for a reduction in the rate of use of corn herbicides, and there are currently no strong economic incentives for corn growers to move in this direction.

The use of insecticides on corn also increased substantially during the last 10 years, although not nearly to the same degree as that of herbicides. Corn is subject to attack by a considerable number of soil and foliar insects. Soil insects are much more important economically than those feeding above ground. More than 90% of the quantities of insecticides used on corn are used against soil insects. In the Midwest, corn rootworms are largely resistant against chlorinated hydrocarbon insecticides; they are controlled by organic phosphate and carbamate insecticides. Up to the present, chlorinated hydrocarbon insecticides, primarily aldrin, were the insecticides of choice against the remaining corn soil insects such as wireworms, cutworms, white grubs, seed beetles and maggots, and others.

Approximately 50% of all corn acres harvested for grain currently are treated with insecticides. It is estimated that less than half of this acreage, or about 20% of the total corn acreage harvested for grain, actually requires insecticide treatments. Thus, it appears that at least 50% of the quantities of soil insecticides used on corn could be saved.

One important prerequisite to eliminating unnecessary insecticide treatments on corn is the development and implementation of practical methods for diagnosing corn soil insect problems, and for predicting treatment needs. Progress in this direction is being made in several corn pilot pest management programs.

The chlorinated hydrocarbon insecticides used on corn are relatively inexpensive. At current prices, the cost of an aldrin application at 1.5 lb of active ingredient per acre of corn, about $2.20, is equivalent to the farm price for 2/3 bu of corn. Thus, there is no compelling economic reason for corn growers to worry whether or not such a treatment is needed. However, most of the organic phosphate and carbamate insecticides are considerably more expensive, providing a greater built-in economic incentive to avoid unnecessary use.

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SECTION VI

PESTICIDE USE PATTERNS ON SORGHUM

PRODUCTION OF SORGHUM IN THE UNITED STATES

Sorghum is a major feed crop in the United States. Table 15 summarizes the U.S. sorghum acreage, yield, value, and production during the last 4 years, 1971 to 1974. The sorghum acreage planted for all purposes ranged from a low of 17.3 million acres in 1972 to a high of 20.8 million acres in 1971. In each of the 4 years covered in Table 15, about 80% of the total sorghum acreage planted for all purposes was harvested for grain.

Sorghum yields (per acre harvested for grain) ranged from 44.9 bu in 1974 to 60.5 bu in 1972. The average price of sorghum received by farmers doubled between 1971 and 1973, increasing from $1.06/bu in 1971 to $2.13/bu in 1973. The farm value per acre of sorghum harvested for grain increased from $56.92 in 1971 to $82.89 in 1972, and further to $125.24 in 1973.

The total production of grain sorghum during the 4-year period ranged from a low of 609.3 million bushels in 1974 to a high of 936.6 million bushels in 1973.

Figure 4 presents the geographic distribution of the U.S. sorghum acreage planted for all purposes in 1971. The leading sorghum producing states in the U.S., in decreasing order of acreage, are: Texas, Kansas, Nebraska, and Oklahoma. All other states planted less than 1 million acres of sorghum for all purposes in 1971.

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Table 15. U.S. SORGHUM ACREAGE, YIELD, VALUE AND PRODUCTION, 1971-1974

Acreage, yield, value, production	Year 1971	 1972	 1973	 1974
Acreage planted for all purposes, 1,000 acres	20,756	17,300	19,300	17,700[b/]
Acreage harvested for grain, 1,000 acres	16,301	13,368	15,940	13,583[b/]
Yield,[a/] bu/acre	53.7	60.5	58.8	44.9[b/]
Average farm price, $/bu	1.06	1.37	2.13	c/
Farm value, $/acre	56.92	82.89	125.24	c/
Total production, million bussels	875.8	809.3	936.6	609.3[b/]

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a/ Yield per acre harvested for grain.
b/ Preliminary.
c/ Not available at this time (January 1975).

Sources: U. S. Department of Agriculture (1973, 1974a,c).

Table 15. U.S. SORGHUM ACREAGE, YIELD, VALUE AND PRODUCTION, 1971-1974

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Acreage harvested for grain, 1,000 acres	16,301	13,368	15,940	13,583[b]
Yield,[a] bu/acre	53.7	60.5	58.8	44.9[b]
Average farm price, $/bu	1.06	1.37	2.13	c/
Farm value, $/acre	56.92	82.89	125.24	c/
Total production, million bussels	875.8	809.3	936.6	609.3[b]

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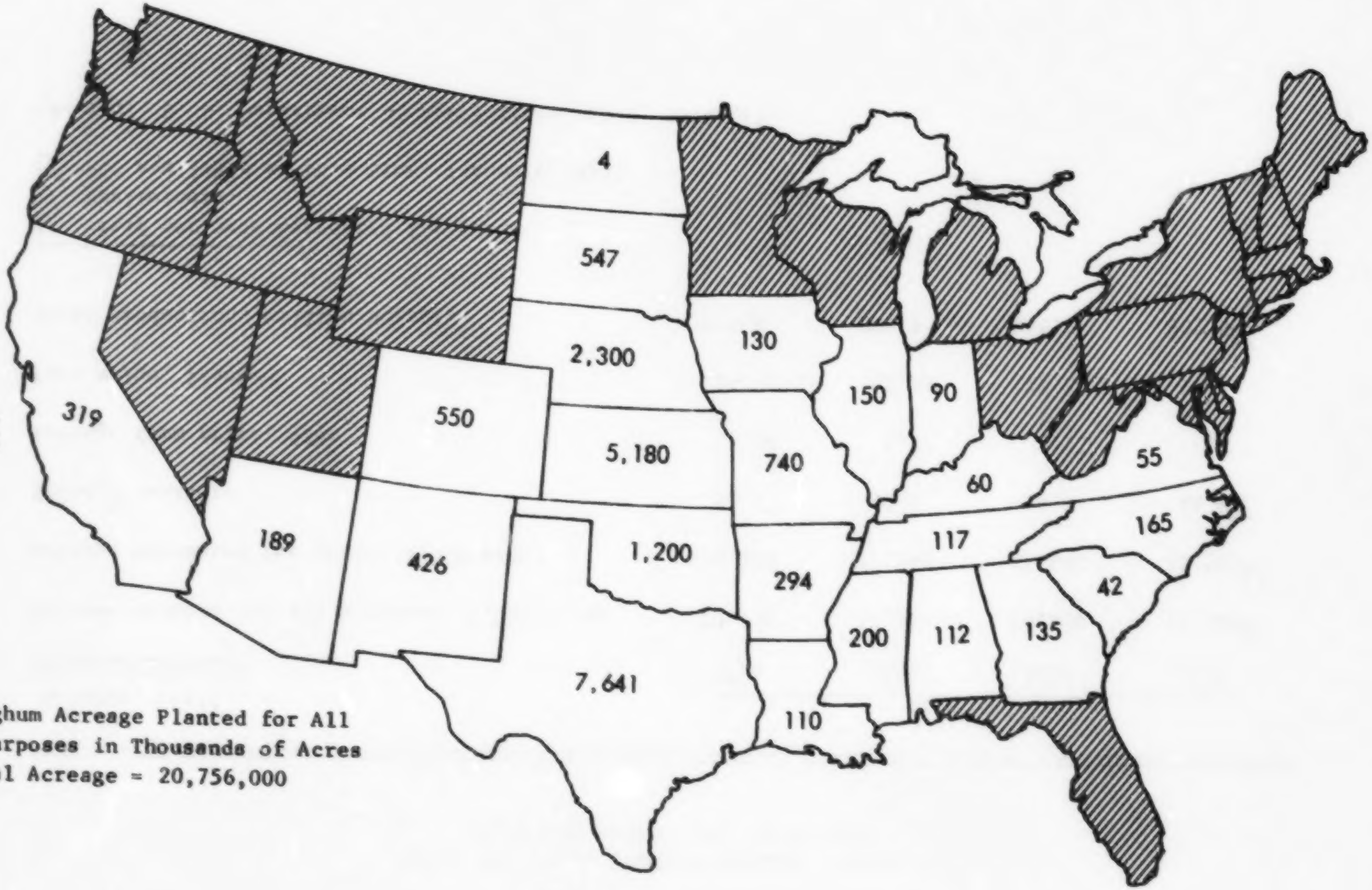
a/ Yield per acre harvested for grain.
b/ Preliminary.
c/ Not available at this time (January 1975).

Sources: U. S. Department of Agriculture (1973, 1974a,c).


4
547
2,300
5,180
1,200
7,641
550
426
189
319
130
740
294
110
150
90
60
117
200
112
135
42
165
55

Sorghum Acreage Planted for All
Purposes in Thousands of Acres
Total Acreage = 20,756,000

Figure 4. U.S. sorghum acreage (1971), by state.

QUANTITIES OF PESTICIDES USED ON SORGHUM

The U.S. Department of Agriculture (1974b) conducted a survey of the use of pesticides by American farmers in 1971. According to this source, sorghum ranked fifth among individual crops in total volume of herbicides used (preceded by corn, soybeans, cotton, and wheat), and fourth in volume of insecticides used (preceded by cotton, corn and peanuts). The use of fungicides, miticides, fumigants, desiccants, plant growth regulators and other pesticides on sorghum is so small that these uses were not disaggregated in the USDA pesticide use report for 1971 (or for prior years).

Further details on the use of pesticides on sorghum in 1971 are provided in Tables 16 and 17. These data are based on the 1971 pesticide use survey (U.S. Department of Agriculture, 1974b). The USDA report does not break down individual pesticide uses on sorghum by regions and therefore had to be supplemented by estimates in Table 17.

Table 16 shows that farmers used 11.5 million pounds of herbicides, and 5.7 million pounds of insecticides on sorghum in 1971. About 81% of all herbicides, and about 74% of all insecticides applied to sorghum were used in the Northern and Southern Plains States, in line with the geographic distribution of the sorghum acreage throughout the U.S. (Figure 4). The Corn Belt States used 10.2% of all herbicides, and 1.6% of all insecticides used on sorghum. Figure 4 suggests that these uses occurred primarily in the State of Missouri. Small quantities of sorghum herbicides and insecticides were used in the remaining sorghum-producing states.

The use of herbicides on sorghum in 1971 by major products and by geographic regions is detailed in Table 17 and will be further discussed below in the section on sorghum herbicide use practices.

Table 18 presents a comparison of the quantities of pesticides used on sorghum in the United States in 1964, 1966, and 1971 according to the USDA pesticide use surveys for these years (U.S. Department of Agriculture, 1968, 1970, 1974b). The total quantity of herbicides used on sorghum increased by 100%, from 2.0 million pounds in 1964 to 4.0 million pounds in 1966, then to 11.5 million pounds in 1971, an almost three-fold further increase from 1966 to 1971. The use of insecticides on sorghum increased from 767,000 lb in 1966 to 5.7 million pounds in 1971, a more than seven-fold increase. (Disaggregated data on the use of insecticides on sorghum in 1964 are not available from the USDA survey.)

Table 16. PESTICIDE USAGE ON U.S. SORGHUM CROP IN 1971

	By Region[a]					
	Herbicides		Insecticides		Total Pesticides[b]	
Region	1,000 lb	%	1,000 lb	%	1,000 lb	%
Northeast	14	0.1	--	0.0	14	0.1
Lake States	--	0.0	--	0.0	--	0.0
Corn Belt	1,176	10.2	94	1.6	1,270	7.4
Northern Plains	5,834	50.6	1,301	22.7	7,135	41.3
Appalachian	310	2.7	28	0.5	338	2.0
Southeast	125	1.1	406	7.1	531	3.1
Delta States	287	2.5	339	5.9	626	3.6
Southern Plains	3,486	30.2	2,927	51.1	6,413	37.1
Mountain	251	2.1	398	7.0	649	3.7
Pacific	55	0.5	236	4.1	291	1.7
Totals	11,538	100.0	5,729	100.0	17,267	100.0

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[a] Source: "Farmers Use of Pesticides in 1971--Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

[b] Fungicides and miscellaneous pesticides are not listed separately in the above report, and are not included in this table.

Table 17. HERBICIDES USED ON SORGHUM, BY REGION, 1971[a,b]
(1,000 lb)

	Region										
Herbicide	North-east	Lake States	Corn Belt	Northern Plains	Appa-lachian	South-east	Delta States	Southern Plains	Moun-tains	Pacific	Total
Atrazine	5	-	400	2,600	160	75	115	700	110	10	4,175
Propazine	-	-	350	500	20	5	30	1,680	-	-	2,585
2,4-D	4	-	200	1,000	60	20	45	600	100	10	2,039
Propachlor	3	-	100	1,250	-	-	50	20	-	10	1,433
Norea	-	-	50	200	50	5	10	100	-	3	418
Arsenicals	-	-	10	-	10	10	20	100	20	15	185
MCPA	-	-	10	70	-	-	-	20	14	5	119
Others	2	-	56	214	10	10	17	266	7	2	584
Total	14	0	1,176	5,834	310	125	287	3,486	251	55	11,538

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a/ Figures for total use of each herbicide and regional totals were obtained from "Farmers' Use of Pesticides in 1971--Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

b/ Use of each individual herbicide, by region, is an MRI estimate.

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Table 18. USE OF PESTICIDES ON SORGHUM IN THE U.S. IN 1964, 1966, AND 1971

Type of pesticide	Year		
	1964	1966	1971
	1,000 lb of active ingredients		
Fungicides	N.A.	N.A.	N.A.
Insecticides[a]	N.A.	767	5,729
Herbicides[a]	1,966	4,031	11,538
Miscellaneous pesticides	N.A.	40	N.A.
All pesticides	1,966[b]	4,838[c]	17,267[d]

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[a] Excluding petroleum.
[b] Herbicides only.
[c] Excluding fungicides.
[d] Insecticides and herbicides only.
N.A. = Not available
Sources: U.S. Department of Agriculture (1968, 1970, 1974b)

During the period 1964 to 1974, the total U.S. acreage of sorghum harvested for grain was as follows (U.S. Department of Agriculture, 1973, 1974a):

Year	1,000 Acres
1964	11,742
1965	13,029
1966	12,813
1967	14,988
1968	13,890
1969	13,437
1970	13,568
1971	16,301
1972	13,368
1973	15,940
1974 (Preliminary)	13,583

These data indicate that the sorghum acreage increased by only 9% from 1964 to 1966, while the use of herbicides more than doubled (Table 18). From 1966 to 1971, the sorghum acreage increased by 27%, while the use of insecticides increased more than seven-fold, and the use of herbicides nearly tripled.

During the last 3 years, the sorghum acreage harvested for grain has decreased somewhat from the record high acreage in 1971.

Thus, while the sorghum acreage appears to be on a slightly upward trend, with considerable year-to-year variations, the use of insecticides and herbicides on sorghum has increased dramatically.

The USDA pesticide use surveys, supported by Cooperative Extension Service publications from the principal sorghum-growing states, indicate that the use of pesticides other than insecticides and herbicides on sorghum is very small or negligible. Therefore, our study of the efficiency of current pesticide use practices on sorghum was focused on insecticides and herbicides.

HERBICIDE USE PRACTICES

The quantities of herbicides used on sorghum in the U.S. have increased greatly from 1964 to 1971, as documented in the preceding section. In 1964, almost 2.0 million pounds of herbicide active ingredients went on sorghum, 4.0 million pounds in 1966, and 11.5 million pounds in 1971 (Table 18).

The U.S. Department of Agriculture (1972) conducted surveys of the extent of weed control with herbicides in 1959, 1962, 1965, and 1968. Table 19 summarizes the results for sorghum. During the 10-year period covered, the sorghum acreage receiving herbicide treatments increased continually, from 2.1 million acres in 1959 to 7.4 million acres in 1968. The percentage of the total sorghum acreage treated with herbicides increased from 14% in 1959 to 42% in 1968. Of the 7.4 million acres of sorghum treated with herbicides in 1968 according to this survey, 2.9 million acres received only preemergence treatments (at an average cost of $6.30/acre); 4.0 million acres received only postemergence treatments ($3.00/acre); and 500,000 acres received both pre- and postemergence treatments ($7.80/acre).

More recent data on the extent of use of herbicides on sorghum in the U.S. from published sources are not available at this time, to the best of our knowledge. It is estimated that currently, about 70 to 80% of the total U.S. sorghum acreage receives herbicide treatments. This percentage is believed to be even higher for irrigated sorghum.

Table 19. ESTIMATED EXTENT OF CHEMICAL WEED CONTROL ON SORGHUM IN THE U.S., 1959 TO 1968

Year	1959	1962	1965	1968
Acreage treated with herbicides, 1,000 acres	2,093	2,665	5,391	7,363
Percent of total sorghum acres harvested for grain	14%	23%	32%	42%

Source: U.S. Department of Agriculture (1972).

Table 17 presents a breakdown of the herbicides used on sorghum in 1971 by regions and by major individual herbicides. Of the total quantity of herbicides used on sorghum in 1971 according to the U.S. Department of Agriculture (1974b), 81% were used in the northern and southern plains states, paralleling the geographic distribution of the U.S. sorghum acreage (Figure 4). An additional 1.2 million pounds of herbicides (10% of the total) were used in the Corn Belt States. The remaining quantities of sorghum herbicides went into six of the remaining seven regions; no sorghum herbicides were used in the Lake States.

Atrazine and propazine, two chemically related triazine herbicides, were used on sorghum in larger quantities than all other herbicides combined (6.8 million pounds = 59% of the total). 2,4-D (2.0 million pounds) and propachlor (1.4 million pounds) were next, while less than 1 million pounds of active ingredient were used of all remaining sorghum herbicides.

Herbicides are used on sorghum for the control of a considerable variety of weeds including pigweeds, crabgrasses, lamb's-quarters, foxtails, johnsongrass, barnyard grass, field bindweed, cocklebures, and morning glories. Of 27 states that responded regarding sorghum in the 1968 herbicide use survey by the U.S. Department of Agriculture (1972), 19 reported an upward trend in herbicide usage, while eight said their use trend was stationary.

Several extension agronomists whom we contacted in the present study indicated unanimously, and independently of one another, that in their states (including Missouri, Oklahoma, and Colorado), there are many more sorghum acres needing herbicide treatment than are actually being treated.

The Kansas sorghum pest management project in 1973 included a weed element (Mock, 1974a). Objectives for this part of the program included identification of weed species, collection of detailed information on soil type, cropping history, and previous weed control practices, and comparative studies on the effectiveness, costs, and environmental effects of alternative weed control practices including herbicides only, combinations of herbicides and tillage, and tillage only. Sorghum fields were surveyed for species and density of weeds once early in the growing season, and a second time about 3 weeks later. A total of 9,230 acres of sorghum in 86 fields of 51 participating producers were surveyed in 1973. Rough pigweed, also known as redroot pigweed (*Amaranthus retroflexus*), and barnyard grass (*Echinochloa crus-galli*) were found to be the two most abundant weed species. Sixteen additional broadleaf weeds, and 10 additional grass weeds were identified and recorded.

The Kansas Pest Management Project Annual Report for 1973 (Mock, 1974a) states that the benefits to sorghum producers from the weed program are less instantaneous than those from the insect management phase. Program leaders anticipate that identification of existing weed problems will result in better tailored control recommendations for future seasons. In the 1974 sorghum weed management program, all participating farmers were encouraged to leave one area in each field receiving weed control measures untreated in order to obtain information on the effectiveness of different weed control practices. The results of the 1974 program are not available at this time.

Our search of the literature and contacts with extension agronomists in leading sorghum-producing states in this project have not revealed any indications that herbicide treatments are applied on more sorghum acres than needed. One way in which the use of herbicides on sorghum might be improved is the determination of minimum effective rates for individual users. Table 20 summarizes the rates of application of the four leading sorghum herbicides recommended by the Extension Services in the four leading sorghum-producing states. Some of the recommendations span a two to three-fold range. This degree of latitude is probably required to cover all extremes of soil, weather and other use conditions. However, it is often difficult for individual sorghum

Table 20. RATES OF APPLICATION OF MAJOR SORGHUM HERBICIDES RECOMMENDED IN TEXAS, OKLAHOMA, KANSAS AND NEBRASKA[a]

State	Herbicide			
	Propazine[b]	Atrazine[b]	2,4-D[c]	Propachlor[b]
	(lb active ingredient/acre)			
Texas[e]	1.2-3.2	1.2-3.0	0.5-1.0	2.25-2.9[d]
Oklahoma[f]	1.2-3.2	1.0-3.0	0.5-0.75	NR
Kansas[g]	1.25-2.4	2.0-2.4	0.3-0.5	4.0-5.0
Nebraska[h]	NR	2.0-2.4	0.5	4.0

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[a] Rates recommended for broadcast treatment. Band application will reduce amount of herbicide needed.

[b] Preplant or preemergence.

[c] 2,4-D amine postemergence.

[d] Recommended only in combination with propazine in Texas.

[e] Texas A&M University (1973b).

[f] Oklahoma State University (1974).

[g] Nilson et al. (1974).

[h] Furrer et al. (1972).

NR = Not recommended.

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growers to determine application rates optimal for their specific situations. Thus, there seems to be a definite need for the type of information to be obtained in the 1974 Kansas sorghum weed management program, as discussed above.

Depending on the product and rate of application, preemergence treatments of atrazine or propazine, the two most widely used sorghum herbicides, range in cost from about \$4.50 to \$13.00 and more per acre. These costs are substantial in relation to the farm value of sorghum (Table 15) and represent a powerful deterrent to unnecessary and inefficient use of herbicides.

In summary, there is no evidence that chemical herbicides are used on sorghum on more acres than needed. The wide ranges in the rates of application per acre recommended for leading sorghum herbicides suggest the possibility that some users apply higher rates per acre than required for optimal economic returns, and that more specific weed control recommendations, tailored to individual farmers' needs, may result in herbicide savings. However, we found no field research data to prove or disprove this supposition.

The rather high costs of herbicides in relation to the farm value of sorghum, plus the risk of crop injury from overtreatment are practical deterrents to the inefficient and wasteful use of sorghum herbicides.

INSECTICIDE USE PRACTICES

As documented in the section "Quantities of Pesticides Used on Sorghum," the use of insecticides on sorghum increased more than seven-fold from 1966 to 1971, while the sorghum acreage harvested for grain increased by only 27% during the same time.

Disaggregated data on the use of individual insecticides on sorghum are not provided by the U.S. Department of Agriculture (1974b) from its 1971 pesticide use survey. We therefore asked extension entomologists in the leading sorghum-producing states for information on the most important sorghum insecticides in their respective areas. Replies received indicate that in 1973 and 1974, the total quantity of insecticides used on sorghum consisted of the following individual products:

disulfoton	about 50% of total
parathion	about 25% of total
phorate	about 10% of total
other insecticides	about 15% of total

Until recently, sorghum was a crop that required little, if any use of insecticides. After the introduction of hybrid grain sorghum varieties in the late 1950's, the sorghum midge, *Contarinia sorghicola*, became a problem in some sorghum growing areas, especially the Texas High Plains. Texas Agricultural Experiment Station and Extension Service entomologists soon determined that early, uniform planting of grain sorghum on an area-wide basis would cause sorghum blooming to occur early in the season, before midge populations reached damaging levels. Other insect pests of grain sorghum such as the corn earworm (*Heliothis zea*), the corn leaf aphid (*Rhopalosiphum maidis*), the fall armyworm (*Spodoptera frugiperda*), the false chinch bug (*Nysius ericae*) and others require insecticidal control only occasionally (Latham, 1974; Teetes et al. 1974).

Beginning in 1968, a rapidly increasing percentage of the grain sorghum acreage in the major producing states required insecticidal treatment against a new, more virulent strain of the greenbug, *Schizaphis graminum*. The rapid spreading of this new strain, known as biotype "C," throughout the Plains States soon caused insecticide applications on sorghum to become a standard practice. Initially, many sorghum growers made preventive, early season insecticide applications against the greenbug. The Texas Grain Sorghum Producers Association has estimated that the expenditures for insecticides used on grain sorghum in the Texas High Plains increased from an average of $100,000/year prior to 1968 to over $14 million in 1969. It is estimated that in 1971, Texas High Plains grain sorghum producers spent about $10 million for insecticides, applying approximately 3 million pounds of active ingredients to 2.5 million acres of the crop (Teetes et al. 1974).

It soon became apparent that indiscriminate, preventive early season insecticide applications for greenbug may contribute to subsequent increases in mite populations due to destruction of predators which would normally hold these mites in check. Moreover, there are indications that the Banks grass mite, *Oligonychus pratensis*, is becoming increasingly resistant to the pesticides used on sorghum in northern Texas, Oklahoma, and Kansas. This mite is virtually impossible to control with chemicals in southern Texas where production of corn and grain sorghum has decreased greatly for this reason (Teetes et al. 1974).

Furthermore, it was feared that the intensive use of insecticides on grain sorghum may upset the natural balance of predators and parasites on cotton in areas where cotton and sorghum are grown in close proximity, as in northern Texas. At present, there are no serious insect pest problems on cotton in the Texas High Plains and consequently, insecticides have not been widely applied to cotton, and cotton pests are kept in check by their natural enemies. Grain sorghum in this area is believed to serve as a major source of the natural enemies which later are active in cotton. Thus, indiscriminate use of insecticides on sorghum may well have repercussions also on cotton, both directly through insecticide drift, and indirectly by destroying parasites and predators before they migrate from sorghum to cotton.

These factors demonstrated the need for a pest management approach. A sorghum pest management program was established as a joint effort of the Texas Agricultural Experiment Station, the Texas Agricultural Extension Service and the Texas Grain Sorghum Producers Board, the State sorghum commodity organization. The program was initiated in 1973 in the community of Edmonson in Hale, Castro and Swisher counties in the Texas High Plains. Sorghum producers in the program area are progressive farmers who employ production methods representative of the Texas High Plains area. The entire grain sorghum acreage in the program area was under irrigation, some double-row and narrow-row sorghum was grown, and fertilizer and herbicide uses were extensive. The program objectives included maintenance of natural control of greenbugs by beneficial insects to the greatest possible extent, and application of reduced, selective rates of insecticide when pest populations reach economic threshold levels, to reduce control costs and preserve as many beneficial insects as possible (Latham, 1974).

In 1973, the 1st year in which the pest management program was in operation, a total of 18,346 acres of sorghum grown by 68 producers were in the program. Research and extension entomologists who have been closely associated with the greenbug situation throughout the Texas High Plains indicate that the greenbug populations on sorghum in the area in 1973 were the highest since 1969, due to an abnormally dry period during May and June of 1973. It is remarkable that in spite of the unusually heavy greenbug infestation pressure in 1973, pest management program participants used fewer insecticide applications and smaller quantities of insecticides than in 1972, a relatively light infestation year. The data summarized in Table 21 show that the number of insecticide applications per acre was reduced by 23%, the average rate of insecticide applied per acre by 72%, and the cost per acre by 50%, considering only the cost of insecticide and application, by 39% if growers' contributions to scouting costs of $0.50/acre are added to the cost of insecticide and application. Savings in insect control costs of this order are significant in relation to the farm value of sorghum (Table 15).

All participants in the Edmonson (Hale County) pest management program in 1973 used disulfoton in either the granular or liquid formulation for greenbug control. Table 22 presents a complete breakdown of the treatments applied (in terms of formulation and of active ingredient per acre), acres treated, total quantity of insecticide used, and insecticide costs per acre.

Table 21. USE OF INSECTICIDES FOR GREENBUG CONTROL IN THE TEXAS SORGHUM PEST MANAGEMENT PROGRAM IN 1973 COMPARED TO PRE-PROGRAM USE (1972)

	1972	1973	Reduction
Average number of applications per acre	1.20	0.93	23%
Pounds active insecticide applied per acre	1.04	0.29	72%
Cost per acre[a]	$4.35[b]	$2.16[b]	$2.19 = 50%
		$2.66[c]	$1.69 = 39%

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[a] Average of quoted price of four aerial applicators.

[b] Cost of insecticide and application.

[c] Cost of insecticide, application, and 50¢/acre for scouting.

Sources: Latham (1974); Teetes et al. (1974).

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Table 22. USE OF DISULFOTON AGAINST THE GREENBUG ON SORGHUM IN THE HALE COUNTY, TEXAS PEST MANAGEMENT PROGRAM, 1973[a]

Rate of application/acre Formulation	AI (oz)	Acres treated	Percent of program acreage	Total insecticide (lb AI)	% Total insecticide	Insecticide cost/acre[b]
7 lb 15G[c]	16.8	2,713	14.8	2,849	56.1	$2.94
5 lb 15G	12.0	882	4.8	662	13.0	2.10
1/2 pt 6LC[d]	6.0	649	3.5	243	4.8	0.90
1/4 pt 6LC	3.0	420	2.3	79	1.6	0.45
1/6 pt 6LC	2.0	2,338	12.7	292	5.8	0.38
1/8 pt 6LC	1.5	9,057	49.4	883	17.4	0.28
1/10 pt 6LC	1.2	887	4.8	66	1.3	0.18
No Treatment		1,400	7.6	0	0	0
Totals		18,346	100.0	5,074	100.0	

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a/ All treatments gave better than 95% control of the greenbug for the remainder of the season.

b/ Average of prices quoted by four aerial applicators.

c/ 15G = 15% granular.

d/ 6LC = 6 lb/gal liquid concentrate.

AI = Active ingredient.

Sources: Latham (1974), Teetes et al. (1974).

Only 15% of the total program acreage were treated at the highest rate of disulfoton, 7 lb 15% granular (16.8 oz active ingredient) per acre, but this accounted for 56% of the total quantity of insecticide used in the program area. By contrast, a total of 9,944 acres (54% of the program acreage) were treated at the two lowest rates, 1/8 and 1/10 pt 6 lb/gal concentrate (1.5 and 1.2 oz active ingredient) per acre; these treatments accounted for only 18.7% of the total quantity of disulfoton used in the program area. Growers who applied disulfoton at these low rates realized a reduction of 90 to 94% in the cost of insecticide per acre compared to the growers who used the insecticide at the highest rate.

All treatments detailed in Table 22 gave better than 95% control of the greenbug for the remainder of the season. A questionnaire survey of program participants and comparisons of their average yields with county averages showed that the participants did not have any sorghum yield losses from the greenbug in 1973, indicating that the pest management program recommendations adequately protected sorghum yields.

Another important consideration is the effect of insecticides applied for greenbug control on subsequent buildup of spider mites, especially the Banks grass mite. Table 23 summarizes the observations made in the Hale County, Texas, sorghum pest management program in this regard in 1973. Spider mites including the Banks grass mite are considered secondary pests on sorghum in this area. However, once these mites are released from natural control by destruction of their parasites and predators, they may cause more damage to the crop than the greenbug. The data in Table 23 indicate that the use of disulfoton at high rates necessitated subsequent treatment for control of spider mites on 9.2% of the acreage, while only 2.6% of the acres treated at the low greenbug control rates required subsequent chemical control of spider mites. Thus, there appears to be a direct correlation between the use of high rates of disulfoton for greenbug control and the need for subsequent spider mite control.

The Texas High Plains Sorghum Pest Management Program was continued in 1974, but results from the 1974 season are not available at this time. Entomologists connected with the program report that 1974 was an even worse year than 1973 in regard to greenbug infestations. Normal rainfall during the early part of the growing season did not occur, and greenbug infestations reached economic damage thresholds about 2 weeks earlier than usual, with no help whatsoever from spring rain storms that sometimes knock down greenbug populations. Field as well as laboratory observations indicate that the greenbug may be developing resistance to

Table 23. EFFECTS OF DISULFOTON APPLICATIONS AGAINST GREENBUG ON SORGHUM ON SUBSEQUENT TREATMENTS AGAINST SPIDER MITES[a]

Rate of application/acre		Acres treated for	Subsequently treated for spider mites	
Formulation	AI (oz)	greenbugs	Acres	%[d]
7 lb 15G[b]	16.8	2,713	370	13.6
5 lb 15G	12.0	882	0	0
1/2 pt 6LC[c]	6.0	649	60	9.2
1/4 pt 6LC	3.0	420	0	0
1/6 pt 6LC	2.0	2,338	115	4.9
1/8 pt 6LC	1.5	9,057	200	2.2
1/10 pt 6LC	1.2	887	0	0
No treatment		1,400	30	2.1
Total at high rates		4,664	430	9.2
Total at low rates		12,282	315	2.6
Total program acres		18,346	775	4.2

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[a] Observations from the Hale Company, TX sorghum pest management program, 1973.

[b] 15G = 15% granular.

[c] 6 LC = 6 lb/gal liquid concentrate.

[d] % of acres treated for greenbugs.

AI = Active ingredient.

Source: Latham (1974).

the organophosphate insecticides currently used against it. In one location, 95% control of greenbugs was previously obtained at 1 to 2 oz active ingredient of disulfoton per acre while recently, a rate of 2.0 lb active ingredient per acre was required to kill a residual greenbug population. In laboratory tests, a 37-fold increase in tolerance to organophosphate insecticides was found (McIntyre, 1974).

These recent developments have caused considerable concern among the pest management program organizers and participants; their extent and possible effect on the future of sorghum pest management in this area remain to be determined at this time.

Kansas, the second largest sorghum-producing state in the U.S. (Figure 4), also had a sorghum pest management program in 1973, involving 98 producers and 22,406 acres of sorghum in the three southwestern Kansas counties of Haskell, Meade, and Stevens.

In the Kansas program, the use of insecticides was recommended only as labeled because legal considerations did not permit a different course, in the opinion of state and program officials. Secondly, the question whether high or low rates of insecticide favor the development of resistance in target insects is still unresolved among experts. For these reasons, the main emphasis in the Kansas sorghum pest management program was placed on using insecticide at labeled rates, but only when needed (Mock, 1974a, 1974b).

Greenbug infestations developed early in the season in 1973 in the program area and were more severe than in average years. Populations of natural enemies of the greenbug, including lady beetles and lacewings, were high in many fields and in some cases delayed for 10 to 14 days the buildup of greenbugs to economic injury levels. Between mid-July and 5 August, chemical insecticides were applied to about 70% of the program acreage. Other sorghum pests became economically important only occasionally. Corn leaf aphids, armyworms and thrips were problematic only in a few fields.

Mock (1974a) reports that based on a preliminary analysis of scouting data, program participants made an average of 0.77 insecticide applications per field, whereas only 0.5 applications were needed. Comparing insecticide use practices, costs, or yields of sorghum within the program area to those of nonparticipating growers in the same area is of doubtful value, according to Mock (1974a). All Kansas extension personnel involved in the pest management program serve all growers in the area, whether or not they participate in the special program. Therefore, a concerted effort was made to educate the entire community and to encourage others to adopt the same practices employed by the pest management program participants. Thus, it is difficult to identify genuine nonparticipants for purposes of making comparisons with participants.

In one of the three counties involved in the pest management program in 1973 (Meade), a buildup of a parasitic wasp, *Lysiphlebus testaceipes*, was recognized by the field scouts in late July. Greenbug numbers were peaking at this time, but parasitism increased rapidly, and within 10 days of their first appearance, the parasites had decimated greenbug populations, and many fields did not require insecticide treatment. If the pest management program had not been in action, many farmers would undoubtedly have failed to recognize the parasitism and the degree of natural control it afforded, and would have treated needlessly. Instead, only about 50% of the total program acreage in Meade County was treated with insecticides once, and none of the acreage required a second treatment. By contrast, more than 90% of the program acreage in Haskell and Stevens Counties was treated, and a small percentage of the acreage in these counties required a second insecticide application. We calculated from these data as reported by Mock (1974a) that over the entire program area, about 27% fewer acres were treated with insecticides than would have been the case if the program participants in Meade County had not had the benefits of the program.

These data indicate that under the sorghum growing conditions of southwestern Kansas, implementation of pest management procedures could reduce the number of sorghum acres receiving insecticide treatments. No effort was made in this program to determine minimum effective rates of insecticides and consequently, there are no Kansas data on possible reductions in the rate of sorghum insecticides currently recommended and used.

Nebraska, third in U.S. sorghum acreage behind Texas and Kansas (Figure 4), also initiated a sorghum pest management program in 1973. The program was located in Clay County and included 71 cooperators growing 6,865 acres of sorghum. Insecticide use practices of program participants were compared with a sampling of Clay County farmers not in the program in 1973. Preliminary results of this comparison are summarized in Table 24 (U.S. Department of Agriculture, 1974d).

Table 24. USE OF INSECTICIDES ON SORGHUM IN CLAY COUNTY, NEBRASKA, BY PEST MANAGEMENT PROGRAM PARTICIPANTS AND NONPARTICIPANTS, 1973

Relationship to program	No.	Acres grown[a]	Acres treated with insecticides At planting	 Post-emergence	 Total
Participants	71	6,865	1,131 (16.5%)	772 (11.2%)	1,903 (27.7%)
Nonparticipants	47	5,940	585 (9.8%)	1,677 (28.2%)	2,262 (38.0%)

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[a] Acres in the program for participants; all acres grown for nonparticipants.

Source: U.S. Department of Agriculture (1974d).

The pest management project was not underway until 1 April 1973 and could therefore not exert any influence on grower decisions on insecticide use at planting time. Program participants actually treated a higher percentage of their sorghum acreage with insecticides at planting than nonparticipants. However, the impact of the pest management program is demonstrated, in the opinion of Nebraska entomologists, in the postemergence insecticide uses. Program participants made postemergence insecticide treatments on 11.2% of their acreage, while nonparticipants treated 28.2%. Combining both planting time and postemergence treatments, program participants treated 27.7% of their sorghum acres with insecticides, while nonparticipants treated 38.0%. Thus, program participants treated 37% fewer sorghum acres than nonparticipants.

The Nebraska Cooperative Extension Service recommended planting time applications of disulfoton and phorate against greenbugs and corn leaf aphids on sorghum at the rate of 1.0 lb active ingredient per acre in 1974 (Roselle et al. 1974a). These recommendations have been dropped from the 1975 "Insect Control Guide for Corn and Sorghum in Nebraska," (Roselle et al. 1974b), with the explanation: "There is evidence that planting time applications may cause development of resistant greenbugs, complicating chemical control later in the season." Post-plant applications of disulfoton and phorate at 4 to 8 oz active ingredient per acre were recommended in Nebraska in 1974 and will continue to be so recommended in 1975.

As in the Kansas program, no efforts were made in Nebraska in 1973 to determine minimum effective rates of insecticides on sorghum and consequently, no data on this topic are available from the program.

Oklahoma, the fourth-largest sorghum-producing state by acreage, also had a sorghum pest management program in 1973. However, we were unable to obtain data on insecticide use patterns and insecticide use efficiency from that program from published or unpublished sources. Oklahoma's 1974 sorghum greenbug control recommendations generally follow the product label, except that disulfoton is recommended at only 4 to 6 oz active ingredient per acre as a foliar spray (label = 4 to 8 oz active ingredient per acre).

Table 25 summarizes the rates of application of disulfoton, the leading sorghum insecticide, for the control of greenbugs and mites on sorghum recommended by different sources, including the EPA Compendium of Registered Pesticides, the product label, and the Extension Services in the states of Texas, Kansas, Nebraska, and Oklahoma. These rates are compared to minimum effective rates and rates used in pest management programs.

The disulfoton use patterns recommended in the product label are practically identical to those summarized in the EPA Compendium. Comparing these recommendations to those of the four states studied, it is interesting to note that only Kansas and Oklahoma still recommend disulfoton applications at planting time, while Texas and Nebraska do not recommend this practice because it may cause development of resistant greenbugs, prevent buildup of beneficial predators and parasites, and/or result in buildup of mites.

The rates of disulfoton recommended for post-plant foliar application against the greenbug in Kansas and Nebraska are identical to the product label. Oklahoma's recommendations reduce the upper limit of the range for this use pattern to 6 oz active ingredient per acre, a reduction of 25% compared to the label limit, 8 oz active ingredient per acre. The disulfoton rates suggested in Texas for foliar application against the greenbug are considerably lower (about 63%) than the labeled rate. An even lower rate, 1.2 oz of active ingredient per acre (reduction of 70 to 85% compared to the label) provided better than 95% control of greenbugs in field tests in Texas in 1973.

Table 25. RATES OF APPLICATION OF DISULFOTON AGAINST GREENBUG AND MITES ON SORGHUM RECOMMENDED BY PUBLIC AGENCIES AND IN SELECTED PEST MANAGEMENT PROGRAMS

Target pest	Greenbug		Mites[a]	
Type of treatment	At planting, side dress or over row	Foliar application	Foliar application	Reduction
	Ounces active ingredient/acre			
Rate recommended				
- in EPA Compendium[c]	12-16	4-8	8	
- in Product Label[d]	12-16	4-8	8-16	
Texas				
Rate suggested by Ext. Service[e]	-		8	0-50% versus Label
		1.5-3		63% versus Label
Min. effective rate[f]		1-2		75% versus Label
Avg. field use rate				
- 1972 (pre-PM)[f]	16.6			72% versus pre-pest mgmt.
- 1973 (Pest Mgmt)[f]	6.6			
Kansas				
Rate recommended by Ext. Service[g]	16 at planting 8-16 post pltg.	4-8	-	-
Insecticide[b] use in Pest Mgmt. Program[h]				Participants treated abt. 27% fewer acres than nonparticipants
Nebraska				
Rate recommended by Ext. Service[i]	-	4-8	-	-
Insecticide[b] use in Pest Mgmt. Program[j]				Participants treated abt. 37% fewer acres than nonparticipants
Oklahoma				
Rate suggested by Ext. Service[k]	16	4-6	8-16	- 0 to 25% versus Label

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[a] Primarily Banks grass mite.
[b] All insecticides.

Sources:

[c] U.S. Environmental Protection Agency (1972).
[d] Chemagro Div., Mobay Chem. Corp. (1974).
[e] Texas A&M University (1973a).

Sources (continued)
[f] Latham (1974), Teetes et al. (1974).
[g] Brooks and Gates (1974).
[h] Mock (1974a).
[i] Roselle et al. (1974b).
[j] U.S. Dept. of Agriculture (1974d).
[k] Oklahoma State University (1974).

Foliar applications of disulfoton against mites (including the Banks grass mite) are recommended only in Texas and Oklahoma.

In the 1973 sorghum pest management program in the Texas High Plains, program participants used an average of 4.6 oz of active disulfoton per acre, compared to 16.6 oz active ingredient per acre in 1972. This reduction (72%) is especially remarkable because there was greater insect infestation pressure in 1973 than in 1972, as discussed above.

For the Kansas and Nebraska sorghum pest management programs, pesticide use data are not available by individual products, but only for all sorghum insecticides combined. In the Kansas program, participants treated about 27% fewer acres of sorghum with insecticides than nonparticipants. In Nebraska, 37% fewer acres were treated in the program area as compared to nonparticipants.

The purpose of the EPA Compendium cited in Table 25 and in the text above is to ensure that the total amount applied will not exceed the tolerance established for a particular pesticide. The Compendium is not designed to recommend application rates.

These data indicate that substantial quantities of the insecticides used on sorghum against the greenbug could be saved if the preventive, planting time use of insecticides at high rates of application would be replaced by postemergence, foliar application of insecticides only as needed, and at the minimum rates required for yield protection. Based on the foregoing discussion and the data summarized in Table 25, we estimate that such savings could amount to 50 to 60% of the quantities of insecticides currently used on sorghum. In terms of the total quantity of insecticides used on sorghum in the U.S. in 1971 according to the USDA pesticide use survey, 5,729,000 lb of active ingredients (Table 16), savings of 50 to 60% would represent 2.9 to 3.4 million pounds of insecticides.

One element of uncertainty is the potential development of resistance of the greenbug to chemical insecticides. Experiences obtained on other crops (examples include cotton, deciduous and citrus fruits, certain vegetables, and others) indicate, however, that insect resistance problems cannot be overcome, at least not for long, by increasing the rates and frequency of pesticide applications. Thus, the threat of greenbug resistance to insecticides would seem to reinforce, rather than to weaken the need for pest management programs on sorghum.

SUMMARY

Sorghum, a major U.S. feed crop, is produced primarily in the states of Texas, Kansas, Nebraska, and Oklahoma. The use of herbicides and insecticides on sorghum has increased substantially during the last 10 years. Fungicides and "miscellaneous pesticides" such as fumigants, defoliants, desiccants, plant growth regulators and others are used on sorghum either in very small quantities or not at all and were therefore not studied in detail in this project.

Herbicides are used on an ever increasing percentage of the total grain sorghum acreage (currently about 70 to 80%). Extension agronomists and weed scientists believe that many additional sorghum acres should be treated with chemical herbicides. There are no indications that herbicides are currently used on more sorghum acres than needed. Some sorghum growers may be applying herbicides at higher rates per acre than required for optimal economic returns because of lack of individualized information on optimal choice of product(s) and application rate for their specific situations.

The costs of chemical weed control in sorghum are significant in relation to the farm value of the crop, an effective economic deterrent to the inefficient or wasteful use of sorghum herbicides.

The use of insecticides on sorghum has increased rapidly since 1968 when a new, more virulent strain of the greenbug, Schizaphis graminum, spread throughout the major grain sorghum-producing areas. Preventive, high rate, early season insecticide applications against greenbugs may accelerate the development of resistant strains. In addition, such treatments have been shown to destroy natural parasites and predators, thus contributing to subsequent increases in mites, especially the Banks grass mite, Olygonychus pratensis. In areas where both cotton and sorghum are grown, sorghum is believed to be a major source of predators and parasites which later in the season migrate from sorghum to cotton. Decimation of these beneficial insects may thus affect not only sorghum, but also cotton.

Based on careful analysis of pertinent literature, of current sorghum insecticide use patterns, of the results to date of three sorghum pest management programs, and on consultations with entomologists in the leading sorghum-producing states, we estimate that 50 to 60% of the quantities of insecticides currently used on sorghum could be saved if pest management principles and methods would be universally adopted and practiced by grain sorghum producers. Such savings would amount to about 2.9 to 3.4 million pounds of insecticides, based on the 1971 pesticide use survey by the USDA.

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SECTION VII

PESTICIDE USE PATTERNS ON APPLES

PRODUCTION OF APPLES IN THE UNITED STATES

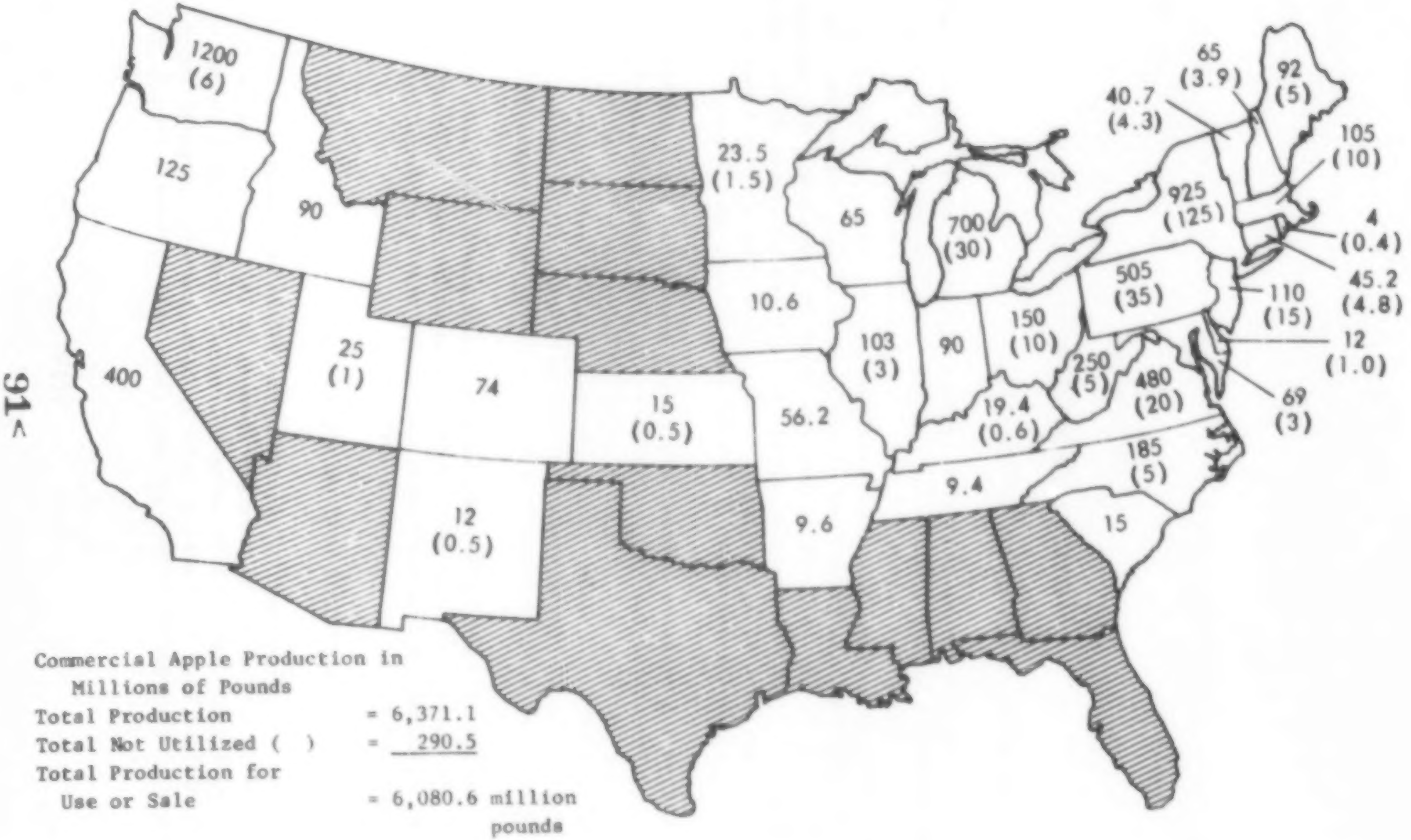
Apples are one of the major fruit crops grown in the United States. Apples were produced commercially on about 526,000 acres in the United States in 1969, the latest year for which acreage statistics for apples have been published (U.S. Bureau of the Census, 1973). In 1973, the total utilized U.S. production of apples was 6.2 billion pounds. The farm value of the 1973 apple crop was about $512 million. The average grower price for all sales of apples in 1973 was estimated at $0.088/lb (U.S. Department of Agriculture, 1974a). Thus, the average value of production of apples was about $1,000/acre at 1973 grower prices.

Figure 5 presents a breakdown of the commercial apple production in the U.S. by states for 1971. The total utilized commercial production of apples in 1971, 6.1 billion pounds, is very close to the 1973 production, 6.2 billion pounds. Thus, the data presented in Figure 5 may be considered to be representative of the geographic distribution of the production of apples in the U.S. for the years 1971 through 1973.

As Figure 5 indicates, the leading apple producing states in the U.S., in decreasing order of volume of production are: Washington, New York, Michigan, and Pennsylvania. All other states produced less than 500 million pounds of apples in 1971.

QUANTITIES OF PESTICIDES USED ON APPLES

The U.S. Department of Agriculture (1974b) conducted a survey on the use of pesticides by American farmers in 1971. According to this source, apples ranked sixth among individual crops in total volume of insecticides used (preceded by cotton, corn, peanuts, sorghum, and soybeans), and second in volume of fungicides used (preceded only by citrus


1200
(6)
125
90
400
25
(1)
74
12
(0.5)
15
(0.5)
23.5
(1.5)
10.6
56.2
9.6
65
103
(3)
700
(30)
90
150
(10)
19.4
(0.6)
9.4
250
(5)
480
(20)
185
(5)
15
505
(35)
925
(125)
40.7
(4.3)
65
(3.9)
92
(5)
105
(10)
4
(0.4)
45.2
(4.8)
110
(15)
12
(1.0)
69
(3)

Commercial Apple Production in
Millions of Pounds
Total Production = 6,371.1
Total Not Utilized ( ) = 290.5
Total Production for Use or Sale = 6,080.6 million pounds

Figure 5. U.S. commercial apple production (1971), by state.

fruits). The use of herbicides on apples was very small; only 0.09% of all herbicides used in agriculture in the U.S. were used on apples in 1971.

Table 26 presents a breakdown of the pesticides used on apples in the U.S. in 1971 by type of pesticides and by regions. Farmers used 7.2 million pounds of fungicides, 4.8 million pounds of insecticides, 548,000 lb of miscellaneous pesticides, and 197,000 lb of herbicides (all quantities in terms of active ingredients) on apples in 1971.

The Northeastern Region accounted for 40.8% of all fungicides, 65.0% of all herbicides, and 49.8% of all insecticides used on apples. The Pacific Region used the largest share (56.6%) of all "miscellaneous pesticides," used on apples in 1971. About two-thirds of this pesticide category consisted of miticides in 1971. The heavy use of "miscellaneous pesticides" in the Pacific Region is indicative of the serious mite problem on apples in this area.

Of all pesticides used on apples, 43.7% were used in the Northeastern Region, 24.6% in the Midwestern states (Lake States, Corn Belt, and Northern Plains), 16.5% in the Pacific Region, the balance in the remaining apple-producing regions of the U.S. The use of fungicides, insecticides, herbicides, and miscellaneous pesticides on apples in 1971, according to the USDA (1974b) survey, is further detailed in Tables 27 through 30. For each of the four pesticide categories, use data are presented by major products and by geographic regions.

Table 31 presents a comparison of the quantities of pesticides used on apples in the United States in 1964, 1966, and 1971 according to the U.S. Department of Agriculture's pesticide use surveys for these years (U.S. Department of Agriculture, 1968, 1970, 1974b). The total quantity of all pesticides used on apples decreased from 19.6 million pounds (active ingredients) in 1964 to 18.5 million pounds in 1966, and further to 12.8 million pounds in 1971. The quantities of fungicides used on apples changed relatively little, while the quantities of insecticides declined substantially during this 8-year period, i.e., from 10.8 million pounds (active ingredients) in 1964 to 8.5 million pounds in 1966, and further to 4.8 million pounds in 1971.

Table 26. PESTICIDE USAGE ON U.S. APPLE CROP IN 1971 BY REGION

	Fungicides		Herbicides		Insecticides		Misc. Pesticides		Total Pesticides	
Region	1,000 lb	%	1,000 lb	%	1,000 lb	%	1,000 lb	%	1,000 lb	%
Northeast	2,943	40.8	128	65.0	2,403	49.8	116	21.1	5,590	43.7
Lake States	1,026	14.3	-	-	349	7.2	29	5.3	1,404	11.0
Corn Belt	853	11.8	11	5.6	831	17.2	36	6.6	1,731	13.5
Northern Plains	12	0.2	-	-	5	0.1	-	-	17	0.1
Appalachian	1,353	18.8	1	0.5	359	7.4	27	4.9	1,740	13.6
Southeast	67	0.9	6	3.0	32	0.7	7	1.3	112	0.9
Delta States	-	-	-	-	-	-	-	-	-	0
Southern Plains	-	-	-	-	-	-	-	-	-	0
Mountain	16	0.2	-	-	44	0.9	23	4.2	83	0.7
Pacific	937	13.0	51	25.9	808	16.7	310	56.6	2,106	16.5
Totals	7,207	100.0	197	100.0	4,831	100.0	548	100.0	12,783	100.0

Source: "Farmers' Use of Pesticides in 1971 Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

Table 27. FUNGICIDES USED ON APPLES BY REGION, 1971[a,b]
(1,000 lb)

Fungicide	Regions										
	Northeast	Lake States	Corn Belt	Northern Plains	Appalachian	Southeast	Delta States	Southern Plains	Mountain	Pacific	Total
Captan	1,250	800	400	-	900	-	-	-	2	40	3,392
Other Dithiocarbamates	800	20	200	10	200	-	-	-	2	65	1,297
Dinocap, Dodine, Quinones	600	160	50	1	3	10	-	-	2	95	921
Other Inorganics	65	-	1	-	-	15	-	-	-	460	541
Zineb	50	1	100	-	180	5	-	-	4	170	510
Other Organics	80	30	5	1	9	10	-	-	1	40	176
Maneb	25	-	50	-	40	-	-	-	5	5	125
Ferbam	70	15	-	-	20	5	-	-	-	8	118
Other Copper Compounds	1	-	45	-	-	15	-	-	-	50	111
Copper Sulfate	2	-	2	-	1	7	-	-	-	4	16
Total	2,943	1,026	853	12	1,353	67	0	0	16	937	7,207

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a/ Figures for total use of each fungicide and regional totals were obtained from "Farmers' Use of Pesticides in 1971-Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

b/ Use of each individual fungicide, by region, is an MRI estimate.

Table 28. INSECTICIDES USED ON APPLES BY REGION, 1971[a,b]

(1,000 lb)

Insecticide	North-east	Lake States	Corn Belt	Northern Plains	Appa-lachian	South-east	Delta States	Southern Plains	Moun-tain	Pacific	Total
Inorganics	900	10	500	-	140	3	-	-	-	300	1,853
Azinphosmethyl	500	100	60	-	100	7	-	-	2	200	969
Other Organophosphorus	300	80	35	1	40	2	-	-	3	160 180	641
Carbaryl	300	100	100	-	30	1	-	-	2	50	583
Chlordane	200	50	100	-	10	2	-	-	4	7	373
Parathion	60	5	10	3	15	5	-	-	15	25	138
Endosulfan	100	2	10	-	10	2	-	-	10	2	136
Ethion	35	-	-	-	1	5	-	-	3	25	69
Malathion	-	-	5	-	10	2	-	-	-	4	21
Diazinon	6	2	4	1	-	-	-	-	-	5	18
Bidrin	-	-	4	-	2	-	-	-	3	3	12
Methoxychlor	1	-	2	-	1	-	-	-	1	2	7
Dieldrin	1	-	-	-	-	-	-	-	1	3	5
Other Organochlorine	-	-	-	-	-	-	-	-	-	2	2
Endrin	-	-	-	-	-	2	-	-	-	-	2
TDE (DDD)	-	-	-	-	-	1	-	-	-	-	1
Heptachlor	-	-	1	-	-	-	-	-	-	-	1
Total	2,403	349	831	5	359	32	0	0	44	808	4,831

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a/ Figures for total use of each insecticide and regional totals were obtained from "Farmers' Use of Pesticides in 1971 - Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

b/ Use of each individual insecticide, by region, is an MRI estimate.

Table 29. HERBICIDES USED ON APPLES BY REGION, 1971[a,b/]
(1,000 lb)

	Regions										
Herbicide	North-east	Lake States	Corn Belt	Northern Plains	Appa-lachian	South-east	Delta States	Southern Plains	Moun-tain	Pacific	Total
Other Organic	65	-	1	-	1	-	-	-	-	28	95
Simazine	20	-	5	-	-	1	-	-	-	10	36
Dalapon	25	-	1	-	-	3	-	-	-	5	34
2,4-D	15	-	3	-	-	1	-	-	-	4	23
Dinitro Group	2	-	-	-	-	1	-	-	-	3	6
Diuron	1	-	-	-	-	-	-	-	-	1	2
Trifluralin	-	-	1	-	-	-	-	-	-	-	1
Total	128	0	11	0	1	6	0	0	0	51	197

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a/ Figures for total use of each herbicide and regional total were obtained from "Farmers' Use of Pesticides in 1971-Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

b/ Use of each individual herbicide, by region, is an MRI estimate.

Table 30. MISCELLANEOUS PESTICIDES USED ON APPLES BY REGION, 1971[a,b]
(1,000 lb)

Pesticide	North-east	Lake States	Corn Belt	Northern Plains	Appa-lachian	South-east	Delta States	Southern Plains	Moun-tain	Pacific	Total
Miticides											
Dicofol	1	-	-	-	-	-	-	-	2	3	6
Omite	69	10	28	-	9	-	-	-	2	160	278
Others	32	-	-	-	10	2	-	-	9	30	83
Fumigants	-	-	-	-	-	-	-	-	-	-	0
Defoliants and Desiccants	-	-	-	-	-	-	-	-	-	-	0
Rodenticides	5	-	-	-	-	-	-	-	-	2	7
Plant Growth Regulators	9	19	8	-	8	5	-	-	10	115	174
Repellents	-	-	-	-	-	-	-	-	-	-	0
Total	116	29	36	0	27	7	0	0	23	310	548

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a/ Figures for total use of each pesticide and regional totals were obtained from "Farmers' Use of Pesticides in 1971-Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

b/ Use of each individual insecticide, by region, is an MRI estimate.

Table 31. USE OF PESTICIDES ON APPLES IN THE U.S. IN 1964, 1966, AND 1971

Type of pesticide	1,000 lb of active ingredients		
	1964	1966	1971
Fungicides[a]	7,700	8.496	7,207
Insecticides[b]	10,828	8,494	4,831
Herbicides[b]	N.A.	389	197
Miscellaneous pesticides[c]	1,037	1,119	548
All pesticides	19,565[d]	18,498	12,783

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[a] Excluding sulfur.

[b] Excluding petroleum.

[c] Includes miticides (100% of total in 1964; about 2/3 of total in 1966 and 1971); fumigants (about 1/3 of total in 1966, none in 1964 or 1971); plant growth regulators (none in 1964 or 1966, about 1/3 in 1971).

[d] Excluding herbicides.

N.A. - not applicable

Sources: USDA 1968, 1970, 1974b.

The volume of commercial apple production in the United States during the last 10 years was as follows (USDA 1973, 1974a):

1964	3,120,000 tons
1965	3,001,000 tons
1966	2,825,000 tons
1967	2,793,000 tons
1968	2,723,000 tons
1969	3,355,000 tons
1970	3,129,000 tons
1971	3,040,000 tons
1972	2,935,000 tons
1973	3,102,000 tons

These production data indicate year-to-year changes in the quantities of apples produced in the U.S., probably due largely to different weather conditions, but no definite trends. By contrast, as pointed out above, the USDA pesticide use data indicate a definite downward trend in the quantities of insecticides and "miscellaneous pesticides" used on apples. This reduction in the use of pesticides, especially insecticides, was thus not correlated with changes in the volume of production of apples, but appears to be due to changes in pesticide use practice.

This assumption is borne out by information from the field. For instance, Eves and Chandler (1973) report that the average costs for pesticides in the State of Washington were $86/acre in 1967, and $48/acre in 1973. This decline in costs probably represents an even greater decline in the quantities of pesticides used because the unit costs of pesticides have increased during this period. Likewise, Brann (1974), advised that apple growers in New York are using substantially smaller quantities of pesticides, especially insecticides, on apples in the 1970's than they were using in the 1960's.

As with other crops, wasteful use of pesticides on apples, such as misuse, overuse, and/or unnecessary use may occur through poor management decisions. The data just quoted suggest that substantial progress has already been made during the last 10 years in correcting wasteful pesticide use practices on apples, and in using pesticides more efficiently. In the following subsections, current pesticide use practices on apples will be examined, focusing on opportunities to further improve pesticide use efficiency, and to further reduce wasteful pesticide uses.

FUNGICIDE USE PRACTICES

Table 31 indicates that the quantities of fungicides used on apples in the U.S. changed relatively little from 1964 (7.7 million pounds) to 1971 (7.2 million pounds). In 1971, close to 50% of the total quantity of fungicides used on apples (3.4 million pounds) consisted of captan (Table 27). Dithiocarbamate fungicides (maneb, zineb, ferbam, and others) accounted for an additional 2 million pounds, or 28% of the total quantity of fungicides used on apples. The balance is made up of a number of additional organic and inorganic fungicides.

The fungicides used most frequently on apples according to Table 27 are used primarily for the control of apple scab (*Venturia inaequalis*). Other diseases of apples caused by fungal pathogens requiring control include powdery mildew (*Podosphaera leucotricha*), several species of rusts, rots, and several others.

Apple scab is the single most important fungus disease of apples. The key to successful prevention of economic damage from apple scab is to control primary infections. To be effective, fungicides must be present on susceptible apple tissues before fungus infection takes place, or within a very short period (generally less than 24 hr) after infection. Therefore, most fungicides are used on apples preventively or protectively, that is before lesions caused by the fungal pathogen(s) becomes visible. Preventive or preprogrammed pesticide applications, prior to established need, are potentially wasteful. However, in the case of the fungus diseases of apples, the infection mechanisms of the fungal pathogens, combined with the capabilities of the most widely used fungicides, make it necessary to apply these fungicides on preventive application schedules in areas where climatic conditions and previous experience indicate that fungal infections are likely. Fungicide applications against apple scab are usually started at the "delayed dormant" or "green tip" stages of development of the host, and continued on regular spray schedules into the summer. In the opinion and experience of plant pathologists and apple growers alike, this application pattern is necessary if fungicides are to be used successfully in protecting apples from scab and other fungus diseases. There is little, if any, indication that the fungicides most often used on apples at present could be used with equal success in a basically different manner, in curative (in contrast to preventive) spray programs, or in greatly reduced quantities.

Furthermore, there are no practical, nonchemical alternatives available for control of the apple diseases controlled by these fungicides. No predators, parasites, or other biological agents are known that could be employed in "integrated apple disease management" programs. Thus, at the present state of the art, no practical, proven alternatives to the use of chemical fungicides on preventive, preprogrammed application schedules are available to growers for the control or management of apple diseases.

For these reasons, these use patterns of fungicides on apples cannot be considered to be wasteful, but appear to be necessary as dictated by the biology of the fungal pathogens involved, and the capabilities of the presently used fungicides.

INSECTICIDE USE PRACTICES

Of the 4.8 million pounds of insecticides used on apples in the United States in 1971 (Table 28), 1.9 million pounds, or 38% of the total, consisted of inorganic chemicals, primarily lead arsenate. Among the synthetic organic insecticides, azinphosmethyl (tradename: Guthion®) was used in larger quantities than any other single product; its volume, 969,000 lb, accounted for more than one-half of the quantity of all organophosphate insecticides, or about one-third of all synthetic organic insecticides used on apples. Carbaryl (tradename: Sevin®) was the next largest apple insecticide used in 1971; its volume, 583,000 lb, amounted to about 20% of all organic insecticides. Several smaller volume organic insecticides accounted for the balance of all insecticides used on apples in 1971.

About one-half of all insecticides used on apples in 1971, 2.4 million pounds (active ingredients), were used in the Northeastern Region. An additional 1.2 million pounds, or 25% of the total, were used in the Midwest (Lake States, Corn Belt, and Northern Plains). The Pacific Region used 808,000 lb of insecticides on apples in 1971 (17% of the total), the balance was used in the other apple growing areas, primarily the Appalachian Region.

Comparing these figures to the geographical distribution of apple production in the U.S. (Figure 5), it is evident that the production of apples in the Northeastern Region requires relatively heavier inputs of insecticides than the Pacific Region.

In the past, insecticides were usually applied to apples on preventive, preprogrammed spray schedules. After some time, it became apparent that this practice was very detrimental to beneficial parasites and predators. In the absence of the latter, plant-feeding mites became a severe problem in many apple-producing areas, especially in the Pacific

Northwest. At first, the use of miticides was stepped up, but several species of mites soon became highly resistant to practically all available miticides. This chain of events prompted the development of more selective apple pest control or management procedures, with emphasis on the selection of insecticides, miticides, and application rates and schedules designed to preserve beneficial predators and parasites to the greatest possible extent. As pointed out above, this development has already resulted in a substantial reduction of the total quantities of insecticides used on apples from 1964 to 1971 (Table 31).

In recent years, Integrated Pest Management (IPM) programs were established in several apple-growing states. The objectives of these programs include identification, quantification, and documentation of the pest problems on apples in the area, and development of solutions to these problems by integrating biological, chemical, and other control methods to the greatest degree possible. The ultimate practical objective is, of course, to increase apple growers' profits.

One of the IPM programs on apples was initiated in 1972 in the Yakima Valley in the State of Washington. Apples are grown on about 36,000 acres in the Yakima Valley. that is about 40% of the total acreage of apples in the state (Table 32). In 1973, 665 acres of apples were included in this program. In the program area as well as in neighboring apple orchards, populations of codling moths, mites, and other apple pests were monitored regularly by mite counts, sex pheromone traps, and intensive field observation. Participating growers received specific spray recommendations from IPM program personnel.

Table 32. APPLE ACREAGE IN WASHINGTON

Total acres of apples in state, 1969[a]	92,244
Total acres of apples in Yakima Valley[a]	36,236
Acres in IPM program in Yakima Valley, 1974[b]	661

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a/ 1969 Washington tree fruit census.

b/ Eves (1974).

Table 33 summarizes the results of this program in 1973 and 1974 as compared to the pesticide use experience on 2,193 comparable acres of apples not under IPM in 1973. In the non-IPM area, a total of 9.31 lb of pesticide active ingredient was applied per acre, at a cost of $59.80/acre. In the IPM area, total pesticide inputs were 3.93 lb/acre ($28.00) in 1973, and 4.5 lb/acre ($29.00) in 1974. Thus, total pesticide inputs in the IPM program in the 2 years averaged 4.2 lb of active ingredient per acre, a reduction of about 55% from the 9.31 lb active ingredient per acre in the non-IPM area. Cost savings per Table 13, all computed on the basis of 1972 prices, were comparable to the savings in quantities. In reality, IPM program participants savings in pesticide costs were even greater than indicated by the data in Table 33 because pesticide costs increased from 1972 to 1974.

Table 33. USE OF PESTICIDES ON APPLES IN THE LOWER YAKIMA VALLEY UNDER IPM VERSUS NON-IPM PROGRAMS

		Acres sprayed against		All pesticides used	
Program	Acres in program	Aphids (%)	Mites (%)	Pound active ingredient per acre	Cost ($/acre)[a]
Non-IPM, 1973	2,193	100	100	9.31	59.80
IPM, 1973	225	0	0	3.93	28.00
IPM, 1974	661	25	28	4.5	29.00

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[a] Basis 1972 prices.

Source: Eves (1974), and Eves and Chandler (1973).

In 1973, no insecticide sprays against aphids or mites were needed in the IPM area, and in 1974, only about one-fourth of the IPM program acreage required such treatments, while in the non-IPM area in 1973, 100% of the acreage was treated against aphids and mites. Project personnel report that when Guthion® is applied against the codling moth at "standard" rates, buildup of mites to damaging proportions often follows, necessitating one or more applications of miticides. Conversely, when used at the minimum rate required for codling moth control, Guthion® permits survival of mite predators, mites are kept at low levels, and chemical miticides are required only occasionally.

Integrated pest management programs on apples in Pennsylvania have been described by Asquith (1972). The Pennsylvania program is also centered on the integration of the biological control of mites with the chemical control of other apple pests. Three different spray schedules are outlined by Asquith. Table 34 summarizes the results of these schedules in terms of total cost per acre, and in terms of the rates of Guthion® (azinphosmethyl) recommended in each schedule. Data on Guthion® were included in Table 34 because it is the organic insecticide most widely used on apples, as documented above (Table 28). Table 34 indicates that the cost of all pesticides combined in the full schedule was $85.15/acre, compared to $60.23 (29% reduction) in the "alternate middles schedule," and $46.12 (46% reduction) in the integrated pest management schedule. The "full schedule" recommends Guthion® applications totaling 6.0 lb 50% wettable powder (WP) per acre per season. In the "alternate middles schedule," this quantity is reduced to 4.0 lb 50 WP (33% reduction), while in the IPM schedule, only 2.0 lb of Guthion® 50 WP are recommended per acre per season, a reduction of 67% from the full schedule.

Table 35 summarizes the rates of application of Guthion® 50% wettable powder for use on apples recommended by different sources, including the EPA Compendium of Registered Pesticides, the product label, and the Cooperative Extension Services in the states of Washington, New York, Pennsylvania, and Michigan. These rates are compared to rates recommended in IPM programs, and minimum effective rates, that is, rates giving economic control in IPM programs.

According to the EPA Compendium (U.S. Environmental Protection Agency, 1972; page III-D-43.1, issued 30 June 1972), Guthion® may be used on apples at the rate of 6.0 lb active ingredient (12.0 lb 50% wettable powder) per acre per application, up to eight times per season, equal to a maximum permissible rate of application of 48 lb active ingredient (96 lb 50 WP) per acre per season. As pointed out previously in the section on sorghum, the EPA Compendium is intended to ensure that the total amount of pesticide applied will not exceed the tolerance; it is not designed to recommend application rates.

The product label (Chemagro Corporation, 1970) recommends 2.0 to 2.5 lb 50 WP/acre/application. The Extension Services' standard recommendations are similar to those on the product label, with a few exceptions. Washington State (1974) recommends up to 3.0 lb 50 WP/acre/application. Pennsylvania (1974) recommends Guthion® only in combination with other insecticides such as lead arsenate, dimethoate, demeton, Imidan, or Zolone. Guthion® as one component of such combinations is recommended at the rate of 0.8 lb 50 WP/acre/application. In New York (Arneson et al., 1974) and Michigan (Jones et al., 1974), the "standard" rate of Guthion recommended is 2.0 lb 50 WP/acre/application.

Table 34. USE OF PESTICIDES ON APPLES IN PENNSYLVANIA UNDER IPM VERSUS NON-IPM PROGRAMS

	Cost of all pesticides		Rate of Guthion® recommended	
Program	$/acre	Reduction versus full schedule	Lb 50 WP/acre /season	Reduction versus full schedule
Full schedule	85.15	-	6.0	-
Alternate middles spray schedule	60.23	29%	4.0	33%
Integrated pest management	46.12	46%	2.0	67%

Source: Asquith (1972).

Table 35. RATES OF APPLICATION OF GUTHION® 50% WETTABLE POWDER ON APPLES RECOMMENDED BY PUBLIC AGENCIES AND IN SELECTED INSECT CONTROL PROGRAMS

Type of recommendation or use	Guthion® 50% WP rate per application		Reduction compared to "standard"
	Per 100 gal.[a/]	Per acre	
Rate recommended			
- in EPA Compendium[e/]		max. 12.0	
- in Product Label[f/]	0.5-0.625[b/]	2.0-2.5	
Washington			
Rate recommended by Ext. Service[g/]	0.25-0.5[c/]	1.5-3.0	"standard"
Rate recommended in IPM Program[h/]		1.25	17-58%
Rate giving economic control in IPM Program[h/]		0.5-1.0	33-83%
New York			
Rate recommended by Ext. Service[i/]	0.5[b/]	2.0	"standard"
Rate used in 1973 IPM Program[j/]		1.43	29%
Pennsylvania			
Rate recommended by Ext. Service[k/]			
- "Standard Program"	0.25[d/]	0.8	"standard"
- "Pest Management Program"	0.08-0.17[d/]	0.25-0.5	38-69%
Michigan			
Rate recommended by Ext. Service[l/]	0.5[b/]	2.0	"standard"
Rate used in 1972 IPM Program[m/]		0.43-0.87	57-79%

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a/ 100 gal. dilute spray.
b/ Basis 400 gal. dilute spray/acre.
c/ Basis 600 gal. dilute spray/acre.
d/ Basis 50 gal. 6 x conc. spray = 300 gal. dilute spray/acre.

Sources:
e/ U.S. Environmental Protection Agency (1972).
f/ Chemagro Corporation (1970).
g/ Washington State University (1974).
h/ Eves (1974).
i/ Arneson et al. (1974).
j/ Brann (1974).
k/ Pennsylvania State University (1974).
l/ Jones et al. (1974).
m/ Thompson et al. (1972).

In Washington State, IPM program participants are using Guthion® successfully at the rate of 1.25 lb 50 WP/acre, a reduction of 17 to 58% compared to the standard. IPM program personnel report that economic control has been obtained at Guthion® rates of 0.5 to 1.0 lb 50 WP/acre, a reduction of 33 to 83% from the standard (Eves, 1974).

In New York, participants in the IPM program in 1973 used Guthion® at an average rate of 1.43 lb 50 WP/acre/application, a reduction of 29% compared to the "standard" (Brann, 1974).

In Pennsylvania, the "pest management program" recommended by Pennsylvania State University (1974) in its 1974 tree fruit production recommendations calls for the use of Guthion® (in combination with at least one other insecticide) at the rate of 0.25 to 0.5 lb 50 WP/acre, a reduction of 38 to 69% against the rates recommended in the "standard program." The rates of other insecticides with which Guthion® is to be combined are similarly reduced in the "pest management program."

In Michigan, Guthion® was used at the rate of 0.43 to 0.87 lb 50 WP/acre in the 1972 and 1973 IPM programs, a reduction of 57 to 79% compared to the standard recommended rate (Thompson et al., 1972; Thompson et al., 1973).

In Table 35, the rates of Guthion® recommended in IPM programs, or found to be economically effective are, on the average, about 50% lower than the "standard" recommended. rates. However, it would be unrealistic to anticipate that the rates of Guthion® currently used on apples in the field could be reduced by 50% across the board. In field practice, Guthion® as well as other apple insecticides are already widely used at rates lower than the "standard." Thus, the potential savings in insecticides suggested by Table 35 have in part already been realized during the past few years, as demonstrated by the decline in the total quantities of insecticides used on apples since 1964. On the other hand, the Guthion® rate data in Table 35 pertain only to single applications. Additional savings in total insecticide inputs would be possible if the number of insecticide applications per season could be reduced. Another possibility of reducing insecticide inputs consists of treating only so-called "hot spots" within orchards, rather than entire blocks. Improved pest monitoring procedures make this approach possible. Further savings in total pesticide input are realized when mite predators are allowed to survive in sufficient numbers to keep detrimental mites under control, thus reducing or eliminating the need for chemical miticides.

In discussing the potential for futher insecticide use reductions with experts in the field, entomologists working on apple insects in New York State pointed out that apple growers in their state have already been using pesticides only "as needed" during the last few years. They see only limited room for saving additional pesticide quantities and costs, of the order of about 10%. Looking for savings greater than 15% would be unrealistic, in their opinion. Somewhat greater reductions in pesticide inputs and costs appear to be possible in Pennsylvania.

Michigan State University's reports on their apple pest management programs for 1972 and 1973 (Thompson et al., 1972; Thompson et al., 1973) do not specify actual or potential savings in pesticide inputs to be expected from the program, and Michigan's 1974 fruit spraying calendar (Jones et al., 1974) does not include separate "standard" and "pest management" spraying schedules.

Entomologists in Washington State believe that substantial reductions in pesticide inputs could be achieved with increased adoption of IPM practices (Eves and Chandler, 1973; Eves, 1974). However, since the Pacific Region uses smaller quantities of pesticides per unit of apple production, savings in that region will have a smaller effect on the total quantities of pesticides used on apples than pesticide use reductions in the Northeastern Region with its heavier use of apple pesticides.

The data in Table 31 show that the quantities of insecticides used on apples in the U.S. have declined substantially between 1964 and 1971. From the information presented above, we estimate that an additional 20 to 30% of the quantities of insecticides that were used on apples in 1971 could be saved, and that this fraction of the total current volume of use of these chemicals might, therefore, be considered inefficient or wasteful. Specifically, this estimate is based on:

* The data summarized in Table 35, showing that the minimum effective rates of Guthion®, a major apple insecticide, are about 50% lower on the average than the "standard" recommended rates.

* The fact that further insecticide inputs could be saved by avoiding insecticide application in the absence of established need for treatment, and by avoiding insecticide or miticide applications necessitated by preceding injudicious pesticide use.

* The opinions of research and extension entomologists working on apple insects in the states of Washington, New York, Pennsylvania and Michigan as discussed above.

* The historical use patterns of insecticides on apples in the U.S. as summarized in Table 31.

Further reductions in the quantities of insecticides used on apples of the order of 20 to 30% would require widespread implementation of integrated pest management practices, vastly improved understanding of IPM principles and procedures by persons making pest management decisions and pesticide applications, and several other prerequisites.

If the USDA estimate on the quantities of insecticides used on apples in 1971, 4.8 million pounds (active ingredient), is representative of the current level of use, a 25% reduction would correspond to 1.2 million pounds. If the USDA estimate is low, then the quantity of insecticides that would be saved by a 25% reduction would, of course, be even greater.

HERBICIDE USE PRACTICES

In 1966, 389,000 lb of herbicides (active ingredient) were used on apples, and 197,000 lb in 1971 (Table 31). In both years, these totals included simazine, dalapon, 2,4-D, and several other organic herbicides not disaggregated in the USDA pesticide use reports (U.S. Department of Agriculture, 1970, 1974b).

Herbicides are used in apple orchards to reduce or remove unwanted vegetation under and around the trees. Heavy growth in these areas may harbor mice, snakes, borers, and other vermin. Weeds compete with trees for water, nutrients, and especially in young plants, light. They may reduce yield and quality of the apple crop and interfere with operations such as fertilization, spraying, harvesting, etc.

Chemical herbicides are used in apple orchards because they are often less expensive and more effective than hand labor or mechanical means of weed removal. The danger of damaging trees by using the wrong products, or by over-application represents a built-in safeguard against misuse and overuse. The herbicides are nearly always applied by ground equipment. Spray drift is rarely, if ever, a problem.

Thus, the use of chemical herbicides in apple orchards does not appear to be wasteful. The quantities of herbicides used for this purpose in 1971 according to the USDA (1974b), 197,000 lb, are relatively small, representing only about 0.09% of the total quantities of herbicides used on agricultural crops in the United States in 1971.

USE OF MITICIDES, FUMIGANTS, AND PLANT GROWTH REGULATORS

Miticides, fumigants, and plant growth regulators are included in a category called "miscellaneous pesticides" in the USDA pesticide use surveys. The use of these products on apples totaled 1,037,000 lb of active ingredient in 1964, 1,119,000 lb in 1966, and 548,000 lb in 1971 (Table 31). As indicated in footnote 3 of Table 31, the 1964 total consisted almost entirely of miticides, including dicofol (Kelthane®), tetradifon (Tedion®), Aramite, and others, unspecified organic miticides. In 1966 and 1971, about two-thirds of all "miscellaneous pesticides" used on apples consisted of miticides. Principal miticides used in 1966 were dicofol, tetradifon, and chlorobenzilate. In 1971, Omite® was the leading miticide.

Miticides

The use of all miticides on apples declined from 1,031,000 lb of active ingredient in 1964 to 673,000 lb in 1966, and further to 367,000 lb in 1971, according to the USDA farm pesticide use surveys. This decline is due primarily to the fact that mites developed resistance to one chemical miticide after another, as indicated by the rapid turnover of products in this group. Integrated pest management programs recently established on apples in several states emphasize biological control of mites. It is anticipated that increased adoption of such programs will result in further reductions in the use of miticides on apples. For instance, in the IPM program in the Lower Yakima Valley in the State of Washington, IPM program participants applied no miticides in 1973, while nonparticipants sprayed 100% of their apple acreage against mites. In 1974, only 28% of the IPM program acreage required miticide treatments (Table 33).

In retrospect, it appears that the extensive use of miticides on apples in the 1960's was economically as well as ecologically inefficient and wasteful. The failure of chemical miticides in major apple-producing areas, especially the Pacific Northwest, prompted the development and implementation of integrated pest management programs. As the miticide use data indicate, these measures have resulted in very substantial reductions in the total quantities of miticides used on apples. Further decreases in the use of miticides on apples are likely to occur with increased adoption of integrated pest management programs.

Fumigants

According to the USDA farm pesticide use surveys, fumigants were used on apples to a significant extent only in 1966. In that year, 395,000 lb of fumigants were included in the total quantity of "miscellaneous pesticides" used on apples. The fumigant total consisted of 269,000 lb of sulfur dioxide and 126,000 lb of other, unspecified fumigants.

Soil fumigation is often recommended in situations where a new orchard is being planted in an old orchard site, for the control of nematodes and other soil-borne pathogens. In such instances, fumigants are applied directly to the soil in the area to be protected. The use of fumigants is a relatively expensive practice, a built-in deterrent to wasteful use. There are no indications that the relatively small quantities of fumigants used on apples are wasteful or inefficient. There are no effective nonchemical methods available to growers for the destruction of soil-borne orchard pathogens that would injure the roots of newly planted apple trees, reduce growth and, in some cases, even kill young trees.

Plant Growth Regulators

Plant growth regulators have been developed and registered for use on apples during the last few years, and as the USDA pesticide use surveys indicate, the use of appreciable quantities of these substances on apples was registered for the first time in the 1971 use statistics. Plant growth regulators are used on apples for several different purposes, including chemical thinning, increase of branch angles, bloom promotion, delay of water core, promotion of color, and prevention of preharvest drop. Misuse or overuse of these substances can produce substantial damage to the quality and/or quantity of the apple crop, or even to the trees themselves. Thus, there is little room for error in the use of plant growth regulators, and it is not likely that they will be used wastefully by apple growers.

SUMMARY

There are no indications that significant quantities of fungicides, herbicides, fumigants or plant growth regulators are used on apples in a wasteful manner.

Most of the commercial fungicides currently available for use on apples have to be applied on preventive, preprogrammed application schedules for optimal biological and economic efficiency and effectiveness. No effective nonchemical methods for the control of fungal diseases of apples are currently available to growers, and no "integrated disease management programs" for apples have been developed at the grower level.

Herbicides, fumigants, and plant growth regulators are used on apples only in relatively small quantities, and in an efficient and effective manner.

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The quantities of insecticides and miticides used on apples declined substantially (about 55%) during the last 10 years. In many apple-growing areas, unilateral reliance on chemicals for the control of apple insects and mites resulted in failure, primarily in the form of unmanageable mite problems. This spawned the development and necessitated the adoption of integrated apple pest management methods. There are indications that substantial further reductions (25 to 50%) in the quantities of insecticides and miticides currently used on apples are possible. Further improvement and large-scale implementation of integrated pest management methods are among the prerequisites needed to make such potential reductions in insecticide inputs a reality.

In relation to the quantities of insecticides (4,831,000 lb) and miticides (367,000 lb) used on apples in 1971 according to the USDA pesticide survey (Tables 28 and 30), savings of the order of 20 to 30% would amount to 1.0 to 1.6 million pounds of insecticide and miticide active ingredients.

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SECTION VIII

WASTES AND LOSSES OCCURRING DURING AND AFTER PESTICIDE APPLICATION

This section presents a summary of the topics discussed in Volume II of this report. Volume II is a detailed discussion of the wastes and losses of pesticides that occur both during and after pesticide application which were examined in this study. The summary given here is divided into the following sections:

* Study Approach;
* Study Areas; and
* Summary of Discussions in Volume II.

Each of these sections are presented below.

STUDY APPROACH

The approach taken in this aspect of the study differed from that used in the studies reported in Sections V, VI, and VII of this volume. Identification of factors that cause pesticide waste and loss both during and after crop treatment was not limited to the three study crops but was made for agriculture in general since many of the techniques used to treat corn, sorghum, and apples are used throughout the agricultural community. Each subject was discussed with reference to agriculture in general when examining the problem areas that cause inefficient pesticide use.

In line with the objective to quantify pesticide waste and losses in as much detail as possible, quantitative aspects of each subject examined were given prime attention throughout this phase of the study. When determining the quantities of pesticides lost or wasted, only the three study crops were considered and all quantities were determined for each crop for the year 1971, the latest year meaningful pesticide use statistics are available.

The information needed for this phase of the study was obtained from a thorough search of the literature, questionnaires, personal, and telephone interviews with persons knowledgeable on the subject matter, and correspondence with agricultural engineers and pesticide equipment manufacturers.

STUDY AREAS

A survey of pesticide wastes and losses caused primarily by physical factors, indicated that substantial losses could cccur both during application and postapplication. At the time pesticides are applied, three mechanisms cause the greatest loss and waste of pesticides; they are: (a) nonuniform pesticide distribution on the crop; (b) overapplication of pesticides; and (c) pesticide drift away from the crop area. After application takes place one of the major pesticide loss mechanisms is transport of the pesticides from the crop by surface runoff and soil erosion. These areas were examined in detail in this study and the discussion of each area is given in Volume II of this report. For the sake of completeness, the wastes and losses of pesticides caused by the miscellaneous discharges of spills and disposal are also described briefly.

The major study areas of this aspect of the study, then, were:

1. Pesticide Wastes and Losses Occurring During Application.

    * Nonuniform Distribution;

    * Overapplication; and

    * Drift.

2. Pesticide Losses After Application and by Miscellaneous Discharge.

    * Runoff and Soil Erosion;

    * Spills; and

    * Disposal.

A summary of the discussions of each of these areas are presented in the next section.

SUMMARY OF DISCUSSIONS AND FINDINGS IN VOLUME II

The topics of discussion and findings on pesticide wastes and losses during and after application are summarized below. The material covered in Volume II of the study deals with agriculture in general and is not limited to corn, sorghum, and apples (except when quantities of pesticides lost or wasted are determined). Many of the findings may apply to other crops to which pesticides are applied in a similar manner.

Each topic discussed in Sections III and IV of Volume II is summarized below and the major findings are given.

Pesticide Wastes and Losses Occurring During Application

The waste of pesticides at the time of application is a result of two major mechanisms: overapplication and nonuniform distribution. Loss of pesticides at the time of application are primarily a result of pesticide drift away from the target area. Both the waste and loss potential of pesticides during application through these mechanisms were examined in this study.

Waste Potential During Application - Waste during application may result from overapplication or nonuniform distribution of pesticides during crop treatment. Overapplication is defined as physically applying pesticides at a rate higher than that intended. Nonuniform distribution means distributing the pesticide unevenly so that some areas of the field receive heavy dosages of pesticide while other areas receive light dosages.

Both overapplication and nonuniform distribution are caused by faulty equipment characteristics and/or erroneous equipment operation. Some of the physical elements of pesticide application equipment that affect the application rate and the uniformity of chemical disbursement are the metering devices, nozzles, and spray tank agitation systems. Some of the more common errors made in operating the application equipment are improper calibration, uneven driving speeds, improper sprayboom height, and choice of unsuitable pesticide formulations. The unique problems of nonuniform aircraft spray disbursement patterns involve both technical and operational aspects.

Overapplication results from:

* Faulty metering devices.

* Nozzle wear with wettable power sprays.

* Improper equipment calibration.

* Driving too slow when turning around, encountering obstacles, or driving up a slope.

* Pesticide formulations mixed in a higher concentration than intended.

Nonuniform distribution results from:

* Faulty metering devices.

* Clogged nozzles.

* Improper spray atomization.

* Inadequate tank agitation systems when spraying emulsions or wettable powders.

* Uneven driving speeds.

* Improper spray boom height, either too low or too high.

* Poor aircraft spray patterns.

The variables which cause these two problems defy quantification in the strict sense. However, these problems are important enough to warrant concern. Overapplication and nonuniform distribution are both current and future problems that must be dealt with if the efficiency of pesticide applications in agriculture is to be enhanced.

Loss Potential During Application - Pesticides are lost into the environment at the time of application when they drift away from the crop being treated and impact away from the target area. Under certain circumstances, these losses are substantial and may pose both an immediate and long-term hazard to the surrounding environment. Drift is neither accidental nor entirely uncontrollable, and its occurrence reduces the efficiency of agricultural pesticide applications.

Drift is a rather complex physical event which is influenced by a variety of interrelated factors. The potential for the occurrence of spray or solid particle drift depends primarily upon meteorological conditions, properties of the particle itself, and operational application techniques. Important factors affecting drift are wind speed and turbulence; particle size and density; evaporation rate of the liquid; spray nozzles and discharge pressures; distance between application equipment and target; and volumes of pesticide formulations applied.

This study took all of these factors into account and estimated the likelihood of drift for various types of equipment and application techniques commonly used in agriculture, paying particular attention to field crops and orchards. The estimations developed in this study are given in Table 36. The biggest drift hazards occur as a result of using dusts and aerial spraying.

In addition to examining drift losses in agricultural chemical crop-treating operations in general, the estimates developed in the study were applied to the three study crops. Between some hard facts and some assumptions in cases where information was unavailable, the losses due to pesticide drift during application were estimated for the applications made to the U.S. corn, sorghum, and apple crops in 1971, the most recent year for which pesticide use statistics on these crops are available. The estimates for pesticide drift loss are included in Table 37, both as percentages and as quantities of active ingredient used that year.

Herbicide losses were low on a percentage basis, but the quantities lost were the largest for the four groups of pesticides. Insecticide losses were the highest in the apple orchards primarily due to the use of dusts and orchard airblasters. Sorghum losses were greater than those of corn since most insecticides used on sorghum are applied by air, whereas corn insecticides are applied to the soil, mostly preemergence. Fungicides and other pesticides are not used on corn and sorghum to any significant extent, while fungicides are used extensively on apples. Again, drift losses were high in the apple orchards for fungicides since some are applied as dusts, and about half as sprays from airblasters.

Pesticide Losses After Application and by Miscellaneous Discharge

Pesticide losses that occur after application that were examined in this study are the result of pesticide transport away from the crop by the natural forces of runoff and soil erosion. Losses which occur through miscellaneous discharges are the result of spills and disposal techniques. Each of these pesticide loss routes are discussed below.

Loss Potential After Application - Pesticide quantities deposited in the target area may impact on the target crop, on the ground, or on other nontarget surfaces in the target area. A portion of the deposit on the crop may be washed off and impact on the ground secondarily at various times after application.

Table 36. LIKELIHOOD OF PESTICIDE DRIFT DURING CROP TREATMENT IN AGRICULTURE BY METHOD OF APPLICATION

Formulation	Equipment type	Pesticide application method[a]	Target	Spray application volume[b]	Estimated percent drift over 1,000 ft from target[c]
Dust	Aircraft, venturi	Air, foliar	Trees	-	70-90
	Airblaster	Ground, foliar	Trees	-	60-80
Spray	Tractor, boom sprayer	Ground, foliar	Plants	ULV	5-10
		Ground, foliar	Plants	LV	1
		Ground, broadcast	Soil	LV	Negligible
		Ground, broadcast	Soil	HV	Negligible
		Ground, band	Soil	ULV	Negligible
		Ground, band	Soil	LV	Negligible
	Tractor, boomless sprayer	Ground, broadcast	Soil	LV	Negligible
		Ground, broadcast	Soil	HV	Negligible
	Spray gun	Ground, foliar	Trees	HV	3-5
	Orchard airblaster	Ground, foliar	Trees	ULV	40-70
		Ground, foliar	Trees	LV	10-40
	Aircraft, boom sprayer	Air, foliar	Trees	ULV	40-60
		Air, foliar	Trees	LV	10-40
		Air, foliar	Plants	ULV	40-60
		Air, foliar	Plants	LV	10-40
		Air, broadcast	Soil	LV	10-40
Granular	Aircraft, venturi	Air, broadcast	Soil	-	1-2
	Spreader, centrifugal	Ground, broadcast	Soil	-	1
	Spreader, boom	Ground, broadcast	Soil	-	1
		Ground, band	Soil	-	Negligible
	Planter	Ground, band	Soil	-	Negligible

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[a] Air refers to pesticide application by aircraft, ground refers to pesticide application by ground rigs.

[b] HV = High Volume; LV = Low Volume; ULV = Ultra-Low Volume.

[c] Assumes a 3 to 5 mph wind; neutral atmospheric stability (S.R. = 0), air temperatures above 60°F; and a relative humidity of 50% or less.

Table 37. ESTIMATED LOSSES DURING AND AFTER APPLICATION OF PESTICIDES TO CORN, SORGHUM AND APPLES (1971)

Pesticide and loss route	Corn		Sorghum		Apples	
	% loss[a]	Lb lost (000)	% loss[a]	Lb lost (000)	% loss[a]	Lb lost (000)
Herbicides						
Drift	0.8-3.0	800-3,000	1.0-3.9	120-450	Negligible	
Runoff	0.5-3.2	500-3,200	0.6-3.4	70-390	Negligible	
Total	1.3-6.2	1,300-6,200	1.6-7.3	190-840	Negligible	
Insecticides						
Drift	0.2-0.7	50- 180	6-25	360-1,400	21-42	1,000-2,000
Runoff	0.3-1.3	80- 330	Negligible		Negligible	
Total	0.5-2.0	130- 510	6-25	360-1,400	21-42	1,000-2,000
Fungicides						
Drift	Negligible		Negligible		21-42	1,500-3,000
Runoff	Negligible		Negligible		Negligible	
Total	Negligible		Negligible		21-42	1,500-3,000
Other pesticides						
Drift	Negligible		Negligible		Negligible	
Runoff	Negligible		Negligible		Negligible	
Total	Negligible		Negligible		Negligible	

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[a] Percent loss refers to the percentage of the amount applied.

The principal mechanisms of pesticide transport away from treated fields after application are: (a) surface runoff including both sediment and water; (b) volatilization; and (c) leaching to groundwater. The magnitude of the losses varies with each pesticide and environmental conditions. Generally, surface runoff and volatilization are the dominant mechanisms for pesticide loss from cropland. Degradation by chemical, physical, or biological processes is not a transport or "avoidable loss" mechanism within the definitions established for this study and was therefore not included in its scope. Volatilization is a process which is beyond the control of the farmer once the pesticide has been properly applied (and soil incorporated, if required). Since this study deals with avoidable losses of pesticides, only surface runoff was studied in detail.

The primary objective in examining the incidence of runoff was to quantify the pesticide losses involved. After defining the variables that affect the amount of runoff that occurs with rainfall and soil management practices in agriculture, two methods were used to try to estimate the quantities of pesticides lost in runoff from the study crops. The first method involved estimating the amount of runoff occurring on the crops and the concentrations of pesticides involved. The second method consisted of estimating the total pesticide loss as a percentage of the amount applied and relating this to the amounts applied to the study crops in 1971.

The first method proved unsatisfactory. Statistics were developed for runoff losses only since soil losses cannot be reasonably estimated for a large crop due to the complexity of the many variables involved. Both annual runoff maps and rainfall maps were used to estimate the runoff from the corn and sorghum crops (apples were not included since soil-applied pesticides are used in small quantities in orchards). Concentrations of herbicides and insecticides in runoff water were determined from field studies reported in the literature. However, quantification of the pesticide losses on the two crops was not undertaken by this method since the variables involved required too many assumptions. There is no current method of accurately determining the amount of runoff from crops, and the work done in this study helps to show why.

The second method was used to quantify the herbicide losses from the corn and sorghum crops in 1971 and the quantities determined are shown in Table 37. The percentages of pesticides lost as a percent of the amount applied were determined from field studies reported in the literature. These percentages were then used with the amount of herbicides actually applied to corn and sorghum in 1971 to determine the loss.

Table 37 shows that herbicide losses from corn and sorghum crops amounted to 3% or less of the amount actually applied to the soil. However, this amounts to as much as 3 million pounds of active ingredient, a substantial quantity.

Miscellaneous Pesticide Discharges - Pesticide losses due to spills and improper disposal were not evaluated in detail in this study. Losses from these two mechanisms reduce the overall efficiency of agricultural pesticide use. However, spills are primarily accidents and disposal techniques are within the control of man. Pesticide accidents as well as losses due to improper disposal of pesticides or containers can be reduced or avoided by improved operator training, performance and supervision.

APPENDIX

CRITERION SCHEME FOR THE SELECTION OF SURVEY CROPS

Many of the parameters to be studied in this project cannot be studied theoretically or in a vacuum, but as they apply to specific crop/pest/pesticide systems. Thus, it is important to select crops suitable as "study systems."

A criterion scheme was developed, in accordance with the provisions of the project work statement (Article I), for this selection. Criteria considered important and evaluated below include the following:

* Volume of use of pesticides on the crop;

* Existence of integrated pest management programs on the crop;

* Crop acreage; and

* Crop farm value.

The question of whether or not integrated pest management programs are in progress on candidate crops is important because these programs will provide information on minimum levels of pesticide use (dosage rate per application, frequency of applications) needed for economic pest control, as opposed to labeled or recommended rates. This type of information is essential to Task 5, The Study of Pesticide Wastes Caused by Management Factors, and is generally not available for crop/pest/pesticide systems that have not yet been studied from the standpoint of integrated pest management.

The volume of use of pesticides by crops and by pesticide category in 1971 has been summarized in Table A-1. This three-part table covers uses of herbicides, insecticides and fungicides, respectively, on those individual crops that account for about 80% of the total use. In each category, crops were ranked in decreasing order of volume of pesticide used, highest volume equals one.

In Table A-2, the number of USDA integrated pest management programs in 1972 and 1973 have been summarized for all crops included in Table A-1. The crops were then ranked in decreasing order of number of IPM programs, largest number of programs equals one.

In Table A-3, the U.S. acreage and farm value of these crops in 1972 (the latest year for which USDA statistics are available) are listed and ranked, largest acreage and largest farm value equals one.

In Table A-4, all rankings from Tables A-1 through A-3 are summarized, totaled, and averaged.

Table A-1. USE OF PESTICIDES ON SELECTED CROPS BY PESTICIDE CATEGORY, 1971

Herbicides				Insecticides				Fungicides			
Crop	MM lb AI	% of total	Rank	Crop	MM lb AI	% of total	Rank	Crop	MM lb AI	% of total	Rank
Corn	101	45	1	Cotton	73	47	1	Vegetables	10	24	1
Soybeans	37	16	2	Corn	26	17	2	Citrus	9	24	2
Cotton	20	9	3	Vegetables	11	7	3	Apples	7	18	3
Wheat	12	5	4	Soybeans	6	4	4	Peanuts	4	11	4
Sorghum	12	5	5	Apples	5	3	5				
Vegetables	6	2	6	Tobacco	4	3	6				
Peanuts	4	2	7	Citrus	3	2	7		—	—	
Subtotals	192	84			128	83			30	77	
All other crops	34	16			26	17			10	23	
All crops	226	100			154	100			40	100	

Source: Andrilenas, P., "Farmers' Use of Pesticides in 1971--Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Dept. of Agriculture (1974).

Table A-2. USDA IPM PROGRAMS BY CROPS, 1972 AND 1973

Crop	Number of programs 1972	Number of programs 1973	Rank
Cotton	14	14	1
Corn	-	6	2
Vegetables	4	4	3
Apples	2	4	4
Sorghum	-	4	5
Peanuts	-	2	6
Citrus	-	1	8
Tobacco	1	1	7
Wheat	-	-	10
Soybeans	-	-	10

Sources: Good, J. M., "1972 Benefit Summaries of Pest Management Projects," Extension Service, U.S. Department of Agriculture, unpublished report (1974).

Good, J. M., "1973 Summaries," U.S. Department of Agriculture and Cooperative Extension Service Pilot Pest Management Projects, Extension Service, U.S. Dept. of Agriculture, unpublished report (1974).

Table A-3. U.S. ACREAGE AND FARM VALUE OF SELECTED CROPS, 1972

	Acreage[a]		Farm value	
Crop	1,000 acres	Rank	1,000 dollars	Rank
Cotton	13,517	5	2,014,230[d]	5
Corn[b]	57,289	1	7,017,381	1
Soybeans[c]	47,755	2	4,451,797	2
Wheat	47,301	3	2,575,089	3
Sorghum[b]	13,546	4	1,041,326	7
Peanuts	1,486	7	477,524	9
Vegetables	3,210	6	2,023,498	4
Apples	N.A.	N.A.	371,455	10
Citrus	N.A.	N.A.	828,021	8
Tobacco	843	8	1,442,801	6

---

a/ Acreage harvested.
b/ For grain.
c/ For beans.
d/ Including lint and seed.

Source: U.S. Department of Agriculture, "Agricultural Statistics 1973," U.S. Government Printing Office, Washington, D.C. (1973).

Table A-4. RANKING SUMMARY BY CROPS

Crop	Table A	Table B	Table C	Table D	Table E	Table F	Total, averaged	Overall rank A-F	Overall rank A, B, and D only
Cotton	3	1	5	1	5	5	3.3	2	1.5
Corn	1	2	5	2	1	1	2.0	1	1.5
Soybeans	2	4	5	10	2	2	4.2	4	4
Wheat	4	10	5	10	3	3	5.8	5	9
Sorghum	5	10	5	5	4	7	6.0	6	6
Peanuts	7	10	4	6	7	9	7.2	10	7.5
Vegetables	6	3	1	3	6	4	3.8	3	3
Apples	10	5	3	4	N.A.	10	7.0	8	5
Citrus	10	7	2	8	N.A.	8	7.0	8	10
Tobacco	10	6	5	7	8	6	7.0	8	7.5

Source: Tables A1-A3.

The averaged totals were then again rated by "overall rank." In the last column in Table A-4, the results of ranking only three criteria, i.e., volume of herbicide use, volume of insecticide use, and number of IPM programs, are given. The rationale for this column is as follows:

- * Fungicides represent only a small share of the total volume of pesticides used on U.S. crops. Therefore, their importance would be overrated if they would be weighted in this ranking system equally with herbicides and insecticides which are used in much larger volume.

- * Total acreage and farm value of a given crop are of lesser importance to the objectives of this study than the other parameters.

Regardless of whether one considers the overall ranks from Tables A-1 to A-3 or from Table A-1, Columns 1 and 2, and Table A-2, the system suggests that the following crops should be considered as candidate study systems: corn, cotton, vegetable, soybeans, sorghum, and apples.

These tentative choices were discussed with the EPA project officer, Mr. Allan Zipkin, at a project meeting at Kansas City on 13 August 1974. Mr. Zipkin advised that EPA realizes the importance of cotton as a pesticide-consuming crop. However, a considerable number of studies have already been performed on cotton, and EPA would be more interested in gathering data on other crops. For these reasons, confirmed in a subsequent telephone conversation between Mr. Zipkin and Dr. von Rümker, cotton was eliminated from further consideration.

Soybeans rated somewhat higher than sorghum in the criterion scheme. Nevertheless, it was decided to give preference to sorghum as a study crop because a preliminary survey of available data indicates that some interesting studies on recommended versus needed rates of insecticides have recently been performed on this crop.

The criterion scheme further indicates that vegetables should receive consideration. However, the high ranking of vegetables in comparison to the other crops is somewhat misleading because, in contrast to all other crops in the ranking system, vegetables are not a single crop, but a group consisting of some 20 major and additional minor crops. To determine if a single vegetable crop might be a suitable study crop, the 1972 acreage and farm value of the 25 vegetable crops considered to be "commercial vegetables" by the U.S. Department of Agriculture were analyzed (Table A-5). In each part of the table, the first 10 crops were ranked in decreasing order of acreage and farm value, respectively, highest acreage and highest farm value equals one.

Table A-5. U.S. ACREAGE AND FARM VALUE OF COMMERCIAL VEGETABLE CROPS, 1972

Crop	Acreage 1,000 acres	Acreage Rank	Farm value 1,000 dollars	Farm value Rank
Artichokes	11.1		8,222	
Asparagus	119.1	8	67,921	
Beans, lima	74.6		18,837	
Beans, snap	341.9	4	107,484	5
Beets	12.7		3,741	
Broccoli	46.8		39,099	
Brussels sprouts	6.6		7,916	
Cabbage	105.6	9	79,978	10
Cantaloupes	97.6	10	94,772	8
Carrots	73.4		95,649	7
Cauliflower	28.2		30,346	
Celery	32.6		104,891	6
Corn, sweet	604.9	1	134,815	4
Cucumbers	178.0	7	90,769	9
Eggplant	3.1		4,568	
Escarole	9.9		9,167	
Garlic	5.1		7,206	
Honeydew melons	12.4		13,082	
Lettuce	219.1	6	277,320	2
Onions	93.3		139,919	3
Peas, green	377.7	3	57,500	
Peppers, green	47.7		58,096	
Spinach	37.8		16,532	
Tomatoes	403.6	2	492,440	1
Watermelons	267.5	5	63,228	
Totals	3,210.3		2,023,498	

Source: U.S. Department of Agriculture, "Agricultural Statistics 1973," U.S. Government Printing Office, Washington, D.C. (1973).

Considering acreage (probably more important regarding pesticide use volume than farm value of the crop), candidate vegetable crops and their usefulness for purposes of this study are as follows:

Sweet corn leads all other vegetable crops in acreage. However, since field corn in already included in the study, we question the desirability of studying sweet corn in addition.

Tomatoes are next. However, EPA has recently funded another study on tomatoes which will probably cover at least some of the parameters to be investigated in this project. We therefore recommend against tomatoes.

Peas, beans, next in line, as well as watermelons, cucumbers, asparagus and cantaloupes are relatively healthy crops which do not generally require high pesticide inputs. Recommend against their selection for this study.

Lettuce and cabbage appear to us to be the relatively most suitable candidate study crops. These crops would then have to be compared against apples, the next candidate crop in line from Table A-4. Among apples, lettuce, or cabbage, we feel compelled to give preference to apples, for the following reasons:

- Apples are an economically more important crop than either lettuce or cabbage in terms of farm value.
- More pesticides are used on apples than on either lettuce or cabbage. The lettuce acreage is 6.8%, the cabbage acreage 3.3% of the total acreage of all commercial vegetables. Assuming an average rate of use of pesticides on all vegetables, about 1 million pounds of insecticides would be used on lettuce and cabbage combined. Even if a relatively higher rate of insecticide use on these two crops is assumed, their combined insecticide use volume would still not approach that of apples, 5 million pounds (Table A-1, Column 2).
- Lettuce and cabbage, like corn and sorghum, are annual row crops. By contrast, apples are a perennial tree crop. Thus, including apples would add an additional dimension to the study, which would not be provided by lettuce or cabbage. Pesticide application methods and equipment for tree crops are different from those for field and row crops.

In summary, based on the criterion scheme and related considerations discussed above, and on our several communications on this matter with the EPA project officer, we propose to select the following three crops as "study systems" for this project:

- Corn;
- Sorghum; and
- Apples.

This selection is, of course, not meant to be absolutely exclusive. As project time and resources permit, we may well study and report on relevant problems pertaining to other crops, especially vegetable crops, in line with EPA's expressed interest in more information on food crops.

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SECTION I

INTRODUCTION

Part II of this report presents the detailed study of the application, postapplication, and miscellaneous losses of pesticides in agriculture which result primarily from physical factors and techniques, as opposed to the pesticide losses which result primarily from use practices (management decisions) that were presented in Volume I. This material is presented in a separate volume since it is both voluminous and technical in nature. Readers that are most interested in the technical aspect of pesticide application and postpesticide application losses will find this volume particularly suited to their needs.

This part is divided into two major sections. The first section examines the pesticide wastes and losses that can occur during application; pesticide overapplication, nonuniform distribution, and drift are the topics covered. The second section examines pesticide losses that can occur after application and by miscellaneous discharges. Pesticide runoff and soil erosion are examined extensively, and losses from spills and disposal techniques are briefly discussed. The discussions in both sections first describe agricultural practices in general. Following these general discussions, the losses that occurred during 1971 by pesticide drift and postapplication (by runoff and soil erosion) are estimated in detail for the herbicides, insecticides, fungicides, and other pesticides used on the three crops--corn, sorghum, and apples--chosen for intensive study on this project (see Volume I).

A general summary of this part of the project is given in Section II. Literature references are given at the end of each section. Appendices A through E summarize details of field studies of drift and runoff, pesticide use on the study crops, and a survey of recommended application rates.

SECTION II

SUMMARY

The topics of discussion and findings on pesticide wastes and losses during and after application are summarized below. The material covered in this volume of the study deals with agriculture in general and is not limited to corn, sorghum, and apples (except when quantities of pesticides lost or wasted are determined). Many of the findings may apply to other crops to which pesticides are applied in a similar manner.

Each topic discussed in Sections III and IV of this volume is summarized below and the major findings of each topic are given.

PESTICIDE WASTES AND LOSSES OCCURRING DURING APPLICATION

The waste of pesticides at the time of application is a result of two major mechanisms: overapplication and nonuniform distribution. Loss of pesticides at the time of application are primarily a result of pesticide drift away from the target area. Both the waste and loss potential of pesticides during application through these mechanisms are discussed below.

Waste Potential During Application

Waste during application may result from overapplication or nonuniform distribution of pesticides during crop treatment. Overapplication is defined as physically applying pesticides at a rate higher than that intended. Nonuniform distribution means distributing the pesticide unevenly so that some areas of the field receive heavy dosages of pesticide while other areas receive light dosages. These mechanisms are two primary contributors to pesticide waste in agriculture during crop treatment.

Both overapplication and nonuniform distribution are caused by faulty equipment characteristics and/or erroneous equipment operation. Some of the physical elements of pesticide application equipment that affect the application rate and the uniformity of chemical disbursement are the metering devices, nozzles, and spray tank agitation systems. Some of the more common errors made in operating the application equipment are improper calibration, uneven driving speeds, improper spray-boom height, and choice of unsuitable pesticide formulations. The unique problems of nonuniform aircraft spray disbursement patterns involve both technical and operational aspects.

Overapplication results from:

* Faulty metering devices.

* Nozzle wear with wettable powder sprays.

* Improper equipment calibration.

* Driving too slow when turning around, encountering obstacles, or driving up a slope.

* Pesticide formulations mixed in a higher concentration than intended.

Nonuniform distribution results from:

* Faulty metering devices.

* Clogged nozzles.

* Improper spray atomization.

* Inadequate tank agitation systems when spraying emulsions or wettable powders.

* Uneven driving speeds.

* Improper spray boom height, either too low or too high.

* Poor aircraft spray patterns.

The variables which cause these two problems defy quantification in the strict sense. However, these problems are important enough to warrant concern. Overapplication and nonuniform distribution are both current and future problems that must be dealt with if the efficiency of pesticide applications in agriculture is to be enhanced.

Loss Potential During Application

Pesticides are lost into the environment at the time of application when they drift away from the crop being treated and impact away from the target area. Under certain circumstances, these losses are substantial and may pose both an immediate and long-term hazard to the surrounding environment. Drift is neither accidental nor entirely uncontrollable, and its occurrence reduces the efficiency of agricultural pesticide applications.

Drift is a rather complex physical event which is influenced by a variety of interrelated factors. The potential for the occurrence of spray or solid particle drift depends primarily upon meteorological conditions, properties of the particle itself, and operational application techniques. Important factors affecting drift are wind speed and turbulence; particle size and density; evaporation rate of the liquid; spray nozzles and discharge pressures; distance between application equipment and target; and volumes of pesticide formulations applied.

This study took all of these factors into account and estimated the likelihood of drift for various types of equipment and application techniques commonly used in agriculture, paying particular attention to field crops and orchards. The estimations developed in this study are given in Table 1. The biggest drift hazards occur as a result of using dusts and aerial spraying.

In addition to examining drift losses in agricultural chemical crop-treating operations in general, the estimates developed in the study were applied to the three study crops. Between some hard facts and some assumptions in cases where information was unavailable, the losses due to pesticide drift during application were estimated for the applications made to the U.S. corn, sorghum, and apple crops in 1971, the most recent year for which pesticide use statistics on these crops are available. The estimates for pesticide drift loss are included in Table 2, both as percentages and as quantities of active ingredient used that year.

Herbicide losses were low on a percentage basis, but the quantities lost were the largest for the four groups of pesticides. Insecticide losses were the highest in the apple orchards primarily due to the use of dusts and orchard airblasters. Sorghum losses were greater than those of corn since most insecticides used on sorghum are applied by air, whereas corn insecticides are applied to the soil, mostly preemergence. Fungicides and other pesticides are not used on corn and sorghum to any significant extent, while fungicides are used extensively on apples. Again, drift losses were high in the apple orchards for fungicides since some are applied as dusts, and about half as sprays from airblasters.

Table 1. LIKELIHOOD OF PESTICIDE DRIFT DURING CROP TREATMENT IN AGRICULTURE BY METHOD OF APPLICATION

Formulation	Equipment type	Pesticide application method[a]	Target	Spray application volume[b]	Estimated percent drift over 1,000 ft from target[c]
Dust	Aircraft, venturi	Air, foliar	Trees	-	70-90
	Airblaster	Ground, foliar	Trees	-	60-80
Spray	Tractor, boom sprayer	Ground, foliar	Plants	ULV	5-10
		Ground, foliar	Plants	LV	1
		Ground, broadcast	Soil	LV	Negligible
		Ground, broadcast	Soil	HV	Negligible
		Ground, band	Soil	ULV	Negligible
		Ground, band	Soil	LV	Negligible
	Tractor, boomless sprayer	Ground, broadcast	Soil	LV	Negligible
		Ground, broadcast	Soil	HV	Negligible
	Spray gun	Ground, foliar	Trees	HV	3-5
	Orchard airblaster	Ground, foliar	Trees	ULV	40-70
		Ground, foliar	Trees	LV	10-40
	Aircraft, boom sprayer	Air, foliar	Trees	ULV	40-60
		Air, foliar	Trees	LV	10-40
		Air, foliar	Plants	ULV	40-60
		Air, foliar	Plants	LV	10-40
		Air, broadcast	Soil	LV	10-40
Granular	Aircraft, venturi	Air, broadcast	Soil	-	1-2
	Spreader, centrifugal	Ground, broadcast	Soil	-	1
	Spreader, boom	Ground, broadcast	Soil	-	1
		Ground, band	Soil	-	Negligible
	Planter	Ground, band	Soil	-	Negligible

---

a/ Air refers to pesticide application by aircraft, ground refers to pesticide application by ground rigs.

b/ HV = High Volume; LV = Low Volume; ULV = Ultra-Low Volume.

c/ Assumes a 3 to 5 mph wind; neutral atmospheric stability (S.R. = 0), air temperatures above 60°F; and a relative humidity of 50% or less.

Table 2. ESTIMATED LOSSES DURING AND AFTER APPLICATION OF PESTICIDES TO CORN, SORGHUM AND APPLES (1971)

Pesticide and loss route	Corn		Sorghum		Apples	
	% loss[a]	Lb lost (000)	% loss[a]	Lb lost (000)	% loss[a]	Lb lost (000)
Herbicides						
Drift	0.8-3.0	800-3,000	1.0-3.9	120-450	Negligible	
Runoff	0.5-3.2	500-3,200	0.6-3.4	70-390	Negligible	
Total	1.3-6.2	1,300-6,200	1.6-7.3	190-840	Negligible	
Insecticides						
Drift	0.2-0.7	50- 180	6-25	360-1,400	21-42	1,000-2,000
Runoff	0.3-1.3	80- 330	Negligible		Negligible	
Total	0.5-2.0	130- 510	6-25	360-1,400	21-42	1,000-2,000
Fungicides						
Drift	Negligible		Negligible		21-42	1,500-3,000
Runoff	Negligible		Negligible		Negligible	
Total	Negligible		Negligible		21-42	1,500-3,000
Other pesticides						
Drift	Negligible		Negligible		Negligible	
Runoff	Negligible		Negligible		Negligible	
Total	Negligible		Negligible		Negligible	

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[a] Percent loss refers to the percentage of the amount applied.

PESTICIDE LOSSES AFTER APPLICATION AND BY MISCELLANEOUS DISCHARGE

Pesticide losses that occur after application are the result of pesticide transport away from the crop by the natural forces of runoff and soil erosion. Losses which occur through miscellaneous discharges are the result of spills and disposal techniques. Each of these pesticide loss routes are discussed below.

Loss Potential After Application

Pesticide quantities deposited in the target area may impact on the target crop, on the ground, or on other nontarget surfaces in the target area. A portion of the deposit on the crop may be washed off and impact on the ground secondarily at various times after application.

The principal mechanisms of pesticide transport away from treated fields after application are: (a) surface runoff including both sediment and water; (b) volatilization; and (c) leaching to ground water. The magnitude of the losses varies with each pesticide and environmental conditions. Generally, surface runoff and volatilization are the dominant mechanisms for pesticide loss from cropland. Degradation by chemical, physical or biological processes is not a transport or "avoidable loss" mechanism within the definitions established for this study and was therefore not included in its scope. Volatilization is a process which is beyond the control of the farmer once the pesticide has been properly applied (and soil incorporated, if required). Since this study deals with avoidable losses of pesticides, only surface runoff was studied in detail.

The primary objective in examining the incidence of runoff was to quantify the pesticide losses involved. After defining the variables that affect the amount of runoff that occurs with rainfall and soil management practices in agriculture, two methods were used to try to estimate the quantities of pesticides lost in runoff from the study crops. The first method involved estimating the amount of runoff occurring on the crops, and the concentrations of pesticides involved. The second method consisted of estimating the total pesticide loss as a percentage of the amount applied, and relating this to the amounts applied to the study crops in 1971.

The first method proved unsatisfactory. Statistics were developed for runoff losses only since soil losses cannot be reasonably estimated for a large crop due to the complexity of the many variables involved. Both annual runoff maps and rainfall maps were used to estimate the runoff from the corn and sorghum crops (apples were not included since soil-applied pesticides are used in small quantities in orchards). Concentrations of herbicides and insecticides in runoff water were determined from field studies reported in the literature. However, quantification of the pesticide losses on the two crops was not undertaken by this method since the variables involved required too many assumptions. There is no current method of accurately determining the amount of runoff from crops, and the work done in this study helps to show why.

The second method was used to quantify the herbicide losses from the corn and sorghum crops in 1971 and the quantities determined are shown in Table 2. The percentages of pesticides lost as a percent of the amount applied were determined from field studies reported in the literature. These percentages were then used with the amounts of herbicides actually applied to corn and sorghum in 1971 to determine the loss.

Table 2 shows that herbicide losses from corn and sorghum crops amounted to 3% or less of the amount actually applied to the soil. However, this amounts to as much as 3 million pounds of active ingredient, a substantial quantity.

Miscellaneous Pesticide Discharges

Pesticide losses due to spills and improper disposal were not evaluated in detail in this study. Losses from these two mechanisms reduce the overall efficiency of agricultural pesticide use. However, spills are primarily accidents and disposal techniques are within the control of man. Pesticide accidents as well as losses due to improper disposal of pesticides or containers can be reduced or avoided by improved operator training, performance and supervision.

SECTION III

PESTICIDE WASTES AND LOSSES OCCURRING DURING APPLICATION

INTRODUCTION

Pesticides are applied to corn, sorghum, and apples to control a wide variety of pests. The use of these pesticides is usually economically advantageous in the production of these crops, but at the same time pesticides can produce undesirable results when inefficiently applied or inadvertently lost to the environment. The ultimate objective of chemical pesticide application is to control unwanted pests in as efficient a manner as possible.

There are several potential sources of waste involved in the application of pesticides, and this section examines three of the more important ones--overapplication, nonuniform distribution, and drift. Each subject is discussed with two objectives in mind. One is to identify the factors which cause pesticides to be wasted, and the other is to quantify the wastes to the extent possible. Therefore, both a qualitative and a quantitative treatment is given to each subject as it is examined and discussed.

The three subjects involve both pesticide overuse and application losses. Overuse is pesticide overapplication and nonuniform distribution during crop treatment resulting from problems associated with the physical characteristics and operation of the application equipment. Application losses involve the drift of chemicals away from the crop at the time the pesticide is applied.

Since the three topics discussed in this section involve pesticide wastes and losses that occur during application, the first section that follows describes the typical pesticide applications that are used in agriculture. The second section discusses problems of overapplication and nonuniform distribution, and the third section discusses pesticide drift.

TYPICAL PESTICIDE APPLICATIONS USED IN AGRICULTURE

An understanding of the pesticide wastes and losses that occur during application requires a working knowledge of the kinds of pesticide applications that are used in agriculture. The most common applications encountered in crop treatment can be conveniently divided into three categories: (a) dust applications; (b) granular applications; and (c) spray applications. Each of these categories are discussed separately below to present the typical formulations, methods of application, and uses of each type of application.

(a) Dust applications - The practice of dusting crops with pesticides has diminished greatly since the 1940's. Over 60% of the aerial applications of pesticides at that time were dust formulations, but by 1963 the percentage had dropped to an estimated 20%.[1] Even less dusting is done today since the problems of drift and low deposit efficiencies of dust particles still remain. There are situations, however, where dust applications are advantageous for good coverage of the crop. Special coverage problems such as dense foliage, vines, and orchards with significant crop depth cannot be penetrated easily by sprays, so dusts are used.

Formulations consist of finely divided solid particles of pesticide that are used in concentrate form or mixed with an inert carrier. Some of the more common carriers are organic flours, lime, talc, gypsum, silicon oxides, bentonites, kaolins, sulfur, volcanic ash, and attapulgite. The concentration of active ingredient in dust formulations is usually low (0.1 to 20%), and most formulations are applied to the crop directly without further dilution.

Particle size of dusts is between 1 and 50 μ. Sizing is conducted by the manufacturers of dusts using a screening operation, and commercial dusts normally range between 30 and 50 μ, while dust concentrates are sized between 1 and 30 μ, with a stated average of 80 to 90% of the formulation below 25 μ.

The method of application used in agriculture employs an airblast technique to blow the dust onto the plants from ground rigs, or employs the use of aircraft to dispense the dusts over the plants. Field crop dusters (rarely used any more) apply dusts directly over plants from booms attached to a blower. Orchard dusters blow the dust up into the trees from automatic nozzles or hand-held guns. Aircraft, both fixed wing and rotary wing, dispense the dust over the crop from venturi devices.

(b) Granular applications - Many of the agricultural herbicides and insecticides are formulated as granules, and the market for granules has risen rapidly in recent years. Granules are used as both preemergent and postemergent herbicides, soil-incorporated insecticides and preemergent fungicides. The market for these products now exceeds 100,000 tons/year.[2]

Formulations consist of inert carriers impregnated with the pesticide. The most common carriers used, in the order of their importance, are: attapulgite, montmorillonite, bentonite clays, granular diatomaceous earths, and vermiculite (almost exclusively used in the home and garden market). Concentration of pesticides in granules range from 2 to 40% active ingredient--the most common concentrations in agricultural pesticides being 5 to 20%. Specific gravities of the products range from 2.0 to 3.0 with the typical formulation having a specific gravity of about 2.5.[2]

Particle size of granules is determined by screening the product after manufacture. Granular products are defined as solids with a particle size between 4 and 80 mesh, U.S. standard sieve size (less than 80 mesh are considered dusts). Granule size is specified for a particular product by labeling it 8/16, 18/35, 20/40, 30/60, etc. This designation means that the product has been screened so that most of the particles are retained on the second screen (large number) after passing through the first screen (small number). The NACA Granular Pesticide Committee has recommended that at least 90% of the product should lie between the two designated screen sizes.[2]

The most common sizes used in agriculture are medium and fine. Soil incorporated insecticides are predominantly the medium sized granules, 18/35 and 20/40; and herbicides and insecticides applied above the soil are usually the finer sizes, 25/50 and 30/60 mesh. The tabulation[3] below shows the U.S. standard sieve series number and the corresponding screen size opening in microns:

U.S. standard sieve number	Screen opening (microns)
35	500
40	420
50	297
60	250
80	177

This tabulation shows that most agricultural granular pesticides have a particle size above 250 μ (60 mesh).

The method of application used in agriculture takes three forms: (a) broadcasting the granules on the soil surface; (b) broadcasting and incorporating the granules into the soil; and (c) applying the granules in bands (rows) either on or below the soil surface. Broadcasting of granules is achieved with either ground or aerial equipment. Ground equipment is normally a tractor-drawn boom that dispenses the granules from nozzles, or a tractor-drawn (or mounted) centrifugal broadcaster. Aerial equipment is normally a fixed-wing aircraft that dispenses the granules from venturi or centrifugal spinning-disc spreaders. Broadcasting and incorporating the granules into the soil can be done by ground equipment dispensing the granules onto the soil ahead of reels or rotary hoe units. Soil incorporation can be a separate operation following the broadcasting of the granules by ground or aerial equipment. Any implement that tills the soil (such as rotary tillers and discs) can be used. Band applications are normally done at the time of planting by dispensing the granules from fan shaped nozzles attached to hoppers mounted on the planter. The granules can be applied ahead of the planter (preplant) and soil incorporated, or behind the planter (preemergent) on the soil surface.

The application equipment operation varies depending upon the method of application. The operating parameters which are typical in agricultural pesticide application of granules are summarized below:

- Aircraft - fly at 90 to 120 mph, release granules at a height of 9 to 12 ft (12 typical).[4/]

- Ground broadcasters - release granules at a height of about 3 ft, both centrifugal and drop-type booms.

- Ground band applications - release granules at a height of about 6 in. or drill into the soil.

(c) Spray applications - The vast majority of herbicides and many of the miticides, insecticides, and fungicides are applied to the crops and crop soil by spray applications. The unique advantage spraying has over granules is that the pesticide can be readily applied to the plants themselves, whereas granules are less adaptive to this use. The significance of spray applications in agriculture was aptly summarized in a report by G. W. Ware[5/] when he quoted the statement "almost all pesticide applications, particularly herbicides, are in the form of sprays, usually water emulsions and wettable powders" (USDA, 1967).

Spray applications vary widely in formulations, methods of application, and application equipment used. To discuss these many variables it is most convenient to separate the spray operations into ground and aerial equipment applications. These two sectors can then be subdivided as required to cover the many facets of operation involved in each sector.

The following discussion addresses ground equipment and aerial equipment separately.

(1) *Ground equipment* - Sprays applied with ground equipment have two primary targets: (a) the crop soil; and (b) the crop plants. Some vector control is employed in agriculture, but it is a relatively small aspect of pesticide use and will receive no consideration in this study. The spraying of crop soil is conducted primarily to apply herbicides for weed control and the spraying of the crop plants is conducted to apply insecticides, miticides, and fungicides to control pests attacking the crop plants.

The types of equipment used for the application of sprays to the soil and to plants growing a short height above the ground (primarily field crops) differs from that for application of sprays to tall plants (mostly trees). Since the application equipment, and, therefore, the technique used is different in each case, the subjects are discussed separately.

Field crops - Field crops are treated nearly exclusively with sprays in applying herbicides to the soil, both preemergent and postemergent, and with sprays in applying insecticides to the plants. Some use of granules and even less of dusts is still practiced in foliar applications but these uses are small in relation to the total quantities of pesticides foliarly applied. Soil application of granular herbicides is small relative to spray formulations, but the use of granular insecticides is still widely practiced. Spray applications of herbicides and insecticides to the soil and foliar applications of insecticides to plants are the topics of discussion in this section.

Formulations consist primarily of wettable powders suspended in water, and water emulsions. Wettable powders are mixtures of active ingredients, inert carriers, surfactants, and adjuvants that can be suspended in water for application. These powders generally contain a high concentration of active ingredient (15 to 95%), and individual particles are normally sized in the same size range as dusts (less than 50 μ), with recommendations that no more than 2% of the powder material should exceed 200 mesh (74 μ).[2] Water emulsions are formed with emulsifiable concentrates (EC), formulations that are solutions of active ingredient and emulsifiers in a solvent. The emulsifiable concentrate is diluted with water before application. Concentrations are typically 15 to 50% for a single active ingredient and as high as 80% for formulations containing an active ingredient mixture.

The *method of application* used in field crops takes three basic forms: (a) broadcasting the spray on the soil; (b) banding the spray on the soil; and (c) applying the spray directly to the plants. Broadcast applications are sprayed from nozzles mounted along a boom or mounted on the spray tank. Booms are tractor-drawn or tractor-mounted and fed from the spray tank. Boomless operations are simply nozzles attached to the sides or back of the spray tank. Band applications are sprayed from nozzles on booms similar to broadcast applications, but cover only a 7 to 14 in. band (row) on the soil. Distances between the bands depend upon the row spacing for the field crop. Foliar applications are the same as band operations, except they apply the spray to the plants instead of the soil. In tall row crops the booms and tractor used to transport the spray nozzles above the plants are high-clearance, self-propelled units, since tractors cannot operate in the field when the plants are present (such as corn).

The nozzles normally used with each type of operation are:

- Soil, broadcast - fan spray and flooding nozzles (boom) and flat spray (boomless).
- Soil, band - fan spray nozzles.
- Foliar - cone and disc-type cone nozzles.

The volume of spray* per acre is generally classified as ultra low volume, low volume, or high volume. Ultra low volume (ULV) is less than 10 gal/acre for soil broadcast, soil band, and foliar applications. Low volume (LV) is 10 to 40 gal/acre for all three operations, and high volume is greater than 40 gal/acre for all three operations (sometimes hundreds of gallons per acre when saturating the foliage with spray solution).

Height of application above the target (soil or plants) varies with each type of application. Soil broadcast operations using booms normally operate at a height of about 12 in. above the soil using flooding nozzles, and from 16 to 24 in. above the soil using fan spray nozzles. Fan spray nozzles are by far the most common in use on booms and are typically operated 18 in. above the ground with about a 50% overlap spray pattern for uniform coverage (fan spray nozzles used in broadcast applications deliver a higher rate of spray in the center of the pattern than at the periphery). Boomless operations normally use flat spray nozzles located 3 ft above the ground. Band applications to the soil primarily employ wide-angle (80, 95, and 110 degrees) fan spray nozzles that distribute the spray

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* The terms ultra low volume, low volume, and high volume are relative terms which are not precisely defined, and the volume per acre associated with each term varies for different types of operations. The volumes of spray per acre associated with ULV, LV, and HV are defined for each type of operation in this report, and are the volumes generally, though not universally, accepted in practice.

evenly across the band width, and are operated 4 to 8 in. above the soil at an average height of 6 in. Foliar applications to field crop plants primarily use cone or disc-type cone nozzles in several various arrangements to spray the plants. Different nozzle arrangements include a single nozzle placed vertically over the plant; two nozzles over the plant at an angle from the vertical; and a three-nozzle arrangement with one nozzle vertically above the plant and the other two nozzles to the side of the plant. The height of the nozzles above the plant are typically 12 in. and the height of the nozzles above the ground, of course, depend on the plant height itself (plus about 12 in.).

The next section discusses the technique of ground application in orchards.

Orchards - Orchards are treated with herbicides, insecticides, fungicides, and miticides. Herbicide treatment of the orchard soil is conducted by ground spray application equipment exclusively since the herbicides commonly used cannot contact the trees without severly damaging them. Insecticides, miticides, and fungicides are sprayed on the trees from airblast machines and spray guns in ground operations.

Formulations consist primarily of wettable powders and emulsifiable concentrates. Herbicides are normally water diluted to provide at least 10 gal/acre of liquid so that application pressures can be maintained low to reduce the drift hazard. Concentrations of insecticides, fungicides, and miticides are normally expressed as 1X, 2X, 3X,* etc. This refers to the amount of water dilution of the concentrate or wettable powder used. The terms refer to dilute (1X) to concentrated (6X or higher) and the volume of water used varies from 400 to 600 gal/acre for 1X concentrations down to about 50 gal/acre for 6X.[6/] Some ultra low volume operations use even less volume, down to the amount of concentrate itself in the case of emulsifiable concentrates.

The method of application used in orchards takes three basic forms: (a) broadcast or spot-treatment of the soil with herbicides; (b) spraying the trees with a high-pressure, high-volume spray technique; and (c) spraying the trees with an airblast technique. Herbicide treatment of the soil is accomplished with tractor-drawn booms for broadcast treatment and backpack sprayers for spot treatment. The booms are operated at low pressures, and high volumes (dilute) of herbicide are used to avoid damaging drift. High-volume, high-pressure applications of foliar pesticides are achieved by wetting the trees to the runoff point

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* The term 1X refers to the normal amount of water used in dilute spraying which has been determined through research and experience over the years. The term 2X means one-half the normal amount of water, 3X is one-third, etc.[2/]

to afford adequate coverage and uniform distribution. Automatic or hand-held spray guns are used, and the spray tank is normally mounted on a truck since the volume of water required is normally 400 to 600 gal/acre. Airblast sprayers, developed in the 1940's, have largely replaced high volume spraying and are either tractor-drawn or truck-mounted units consisting of a spray tank, large blower, and peripheral nozzle arrangements. These sprayers operate on the principle of using air as the transport medium for the pesticide, and function by blowing air laden with pesticide through the trees in large enough quantities to displace the existing air surrounding the tree. The pesticide may be applied in dilute or concentrated formulations.

The volume of application per acre is classified as high volume (more than 50 gal/acre), low volume (about 10 to 50 gal/acre) and ultra low volume (less than 10 gal/acre). High-volume applications are not commonly used today since handling and transporting large volumes of water is time-consuming and expensive. Most orchard spraying is done with low volumes, and some with ultra low volumes.

(2) Aerial equipment - Aerial application of pesticide sprays to treat crops has increased over the past few years. In 1973, statistics kept by the FAA show that 1,869,000 hr were flown by aerial applicators in the United States. The national average figure for acres of crops treated per hour is 80. These statistics show that about 150 million acres of crops were treated by aerial applicators in 1973. The estimate for 1974 is an approximate increase of 20% over the 1973 figure, or about 180 million acres.7/

About 90% of the spray formulations aerially applied to crops are applied in low volumes of 1 to 10 gal/acre.7/ Most of the applications are in the 3 to 5 gal. range. Of the remaining 10%, about half is applied in ULV of 1 gal. or less per acre and the other half at about 20 gal/acre. Since the major pesticides used are applied at the rate of 1 to 2 pt of pesticide solution per acre (undiluted basis) and are formulated to contain 4 lb of active ingredient per gallon, the total amount of active ingredient aerially applied was between 75 and 150 million pounds in 1973.

Sprays applied by aircraft have two primary targets: (a) the crop soil; or (b) the crop plants. Most aerial pesticide applications involve spraying the crop plants with insecticides, fungicides, and miticides. Some soil applications are performed but these are in a minority, since most herbicides are applied as sprays by ground equipment and soil insecticides are commonly applied as granules.

The formulations used in aerial spraying do not differ markedly from those of ground applicators. Wettable powders and emulsifiable concentrates are commonly used with aircraft also.

The method of application takes the form of a broadcast spray over the entire crop, whether treating the plants or the soil. Aircraft, both fixed wing and rotary, have components similar to ground rigs, and continuous spray booms with nozzles spaced about 1 ft apart are mounted below the aircraft to spray the pesticide.

The nozzles normally used with aircraft are hollow cone, but fan spray and jet nozzles are sometimes used to produce coarser droplets.

The volume of spray per acre is either low volume or ultra low volume. Low volume is considered to be 1 to 10 gal/acre, with the typical application rate between 3 and 5 gal/acre. Ultra low volume amounts to spraying the undiluted pesticide concentrate at rates below 1 gal., usually from 1 to 2 pt/acre.

The height of application varies for different types of operations. Applications to the soil are normally applied at heights of 5 to 10 ft over the ground; field crop plants are sprayed at heights of between 10 and 15 ft; and orchards are sprayed at heights just above the trees and vary according to tree heights.

PESTICIDE OVERAPPLICATION AND NONUNIFORM DISTRIBUTION

Overapplication means the dispensing of pesticides to the entire crop at an unintentionally high rate of application, or in heavy doses in a spotty, nonuniform manner. This overuse of chemicals occurs primarily because of equipment problems--either physical or operational. The efficiency with which pesticides are applied to the three study crops depends heavily upon proper use of the application equipment. This equipment invariably has design features or operating characteristics that must receive careful consideration in order to achieve maximum efficiency. Research on application equipment has been concerned for years with improvement in the uniformity of distribution of pesticides, because the required rate of application for many pesticides could be reduced without loss of effective pest control if uniformity of distribution could be attained. Conversely, when pesticides are applied in a spotty or inconsistent manner, more chemicals may be needed in order to achieve the desired results. To the degree that nonuniform application adds to the total amount of pesticide used to achieve effective control, it is a form of overapplication.

Overapplication in a more direct sense involves applying pesticides at a rate higher than that intended. This can be caused by both faulty equipment characteristics and erroneous operation of the equipment. When pesticides are overapplied, regardless of the reason, their use must be considered wasteful and unnecessary.

The discussion of overapplication and nonuniform distribution is divided into two sections. The first section considers the physical features of the application equipment which most affect efficient pesticide application. The second section considers the human element in the operation of equipment and its effects on application efficiency. Each section is followed by a brief statement on the quantification of overapplication and nonuniform distribution.

Physical Equipment Problems

Since the vast majority of pesticides applied to crops are either sprayed or granularly applied, the following discussion is confined to spray equipment and granule application equipment. The equipment features examined in this section affecting the rate and uniformity of application are: (a) metering devices; (b) nozzles; and (c) spray tank agitation.

Metering Devices - Granule applicators all employ some type of metering device to control the rate of application. These devices are primarily responsible for the uniformity of the rate of application. As an example of the problems that can develop with metering devices, consider the drop-type applicator. The most common metering device used on drop-type units is a ground-driven vaned or fluted horizontal rotor-bar agitator between the hopper and an adjustable discharge opening. Other devices include variable orifices with a rubber-flanged impeller; a fixed orifice with a variable screw-conveyor auger; and a variable orifice between the hopper and an oscillating plate.

Once the discharge openings have been set (whether adjustable or fixed), the discharge rate is dependent on, among other things, the speed of the horizontal vaned or fluted rotor that dispenses the granules. Under ideal conditions, the discharge rate is proportional to the rotor speed so that the application rate is unaffected by forward speed of the unit. Unfortunately, this is not usually the case, and as the applicator (which is normally tractor-mounted or tractor-drawn) is used to treat the crop, the speed at which it moves varies. This variation in application speed causes variations in the amount of granules dispensed, and therefore, nonuniform distribution.

The effect speed has on the discharge rate depends on a number of variables including the type of rotor and the size of the granules. Vaned rotors should operate at 7 to 20 rpm, while fluted rotors sometimes operate slightly faster than 20 rpm. If the speed is too low, erratic flow results; if the speed is too high, the granules may be excessively ground. To point out the complexity of this problem, the following excerpt is taken from Principles of Farm Machinery:8/ "Some tests with vane-type rotors have shown decreases in discharge rate as the rotor speed is increased. Other tests with the same types of rotors have shown a moderate increase (but never proportional to speed). In tests with different granule sizes, the rate tended to increase with speed for large granules and to decrease with increased speed when the granules were small. When a rubber, fluted roll . . . was tested, the discharge rate was found to be nearly proportional to speed between 5 and 15 rpm, but there was no change between 25 and 50 rpm."

In addition to variable discharge rates occurring with variable speeds and granule sizes, cyclic rate variations corresponding to the frequency of the vanes passing the discharge opening have been observed. This means that as the applicator moves forward, the amount of granules deposited will vary from small amounts to larger amounts in a cyclic fashion as the rotor revolves and dispenses the pesticide. For example, a six-vane rotor turning at 12.5 rpm and a forward speed of 3 mph, has a cycle whose length is 42 in. along the row. The cyclic variation of the amount of granules deposited on the soil can be significant, and various investigations of this phenomena have shown that the ratios between maximum and minimum cyclic rates for 3- to 5-in. increments ranged from 2:1 to 5:18/ (meaning that two to five times as much pesticide is deposited in heavy dosage areas compared to light dosage areas). Fluted rotors should have smaller cyclic variations than the vane-type rotors since the displacement per flute is smaller than the displacement per vane (vanes protrude a greater distance from the rotor than do flutes). Cyclic variations will also become more severe as the discharge opening is increased, and will increase if impacts are experienced (especially on rough terrain) when operating the applicator.

The nonuniformity of granular pesticide application experienced from cyclic variations and variable rotor speeds is a problem existing in agriculture today. Operating the applicator (normally pulling it behind a tractor) at different speeds when treating the field can cause nonuniform distribution. Generally, lower application will occur when speed is increased, depending upon the variables discussed above. Even if a constant speed were maintained throughout the treatment, the cyclic variations caused by the revolution of the rotor would cause distortions in the application rate. Since from two to five times the minimum dosage rate occurs in the maximum dosage areas, these heavy dosage areas can be considered nonuniform overapplications of the pesticide. If pesticide migration is minimal or the concentration of pesticide in the soil is proportional to the rate applied at any given point, the low dosage rates effect control of the field pest in the areas in which they occur, and the heavy dosage areas receive a wasteful overapplication.

Nozzles - Spray nozzles form the discharge openings in most spray applicators. They are used to direct the flow of liquid, and, in conjunction with the discharge pressure, to control the rate of application and size of the particles sprayed. Nozzles vary according to type, orifice size, and materials of construction. Each of these variables is important in determining the effectiveness and efficiency of the spray application.

There is a wealth of literature on the research that has been done toward the optimization of nozzles to obtain efficient application and uniform distribution of sprays. A brief treatment of the subject will be considered in this section as it applies specifically to the application problems experienced in agriculture.

When nozzles are improperly used, nonuniform distribution and/or overapplication of the pesticide may occur. The basic problems considered here are: (a) improper atomization; (b) clogging; and (c) nozzle wear.

Improper atomization occurs when droplets are formed either too large or too small. If they are too large, coverage is often spotty and nonuniform; if too small, particle drift increases, and deposition on the target surface is less likely. Even if the proper nozzles for good atomization are mounted on a boom-type applicator, problems can still occur. The rate of application in gallons per acre is a function of the spacing of the nozzles on the boom, nozzle orifice size, nozzle pressure, and rate of forward travel. This relationship takes the general form of:

$$\text{(Gallons per acre)} = \frac{\text{(GPM per nozzle) (Constant)}}{\text{Speed (mph)} \times \text{nozzle spacing (in.)}} .$$

The equipment owner normally buys nozzles based on the manufacturer's and seller's recommendations for his particular needs. With a given number of nozzles and the fixed spacing on the boom, the nozzles used will be of a certain orifice size and pressure requirement. However, the operator may decide he wishes to drive faster or (rarely) slower than the speed for which application is calibrated, or to change the concentration of pesticide to be applied. (This occurs most often if the operator uses more than one pesticide or different ones the following year.)

From the above formula it can be seen that driving at higher speeds or using different concentrations causes the rate of application to vary unless the discharge rate from the nozzles is changed proportionately. For faster application speeds, the nozzle output must increase for a given application rate, and for higher application rates, the nozzle output must increase also. To increase the output, two basic adjustments can be made: (a) use large orifice nozzles; or (b) increase the discharge pressure. The tendency to increase pressure is great, particularly if the rate of application is close to the desired one. (This sometimes occurs with the initial purchase of nozzles since they do not always produce the desired effects due to variables in the equipment operation.) However, increasing the pressure produces smaller particles that tend to drift more, and coverage may be inadequate. Decreasing pressure produces the opposite effect in that droplets produced are larger and coverage is often spotty. The main point is that if the rate of application is not the proper one at the time of calibration, a change in operating speed or a change in nozzles should be made rather than a change in the pressure unless the adjustment is a very minor one.

Clogging occurs when nozzles are improperly maintained and is more prevalent with small orifice nozzles. To avoid clogging, frequent cleaning (sometimes daily) should be performed by flushing the nozzles. To remove an obstruction that is plugging the nozzle, a wood splinter can be used. Nails or wires should never be used since they may scratch the precision surfaces and distort the spray pattern. If frequent clogging occurs during operation, nozzles with larger orifices are needed. When clogging does occur, the uniformity of application is, of course, adversely affected.

Nozzle wear has become an increasing problem primarily due to the increased use of abrasive wettable powder formulations. The output of solution increases as nozzles wear and Figure 1[9/] shows how flow will increase due to nozzle wear when spraying a typical wettable powder formulation. This figure shows that brass nozzles wear rapidly and that application rates will increase as the pesticide is applied, resulting in overapplication. Even with the chrome-plated brass nozzles some overapplication will occur if wear during the period of application is not taken into consideration. The use of brass-bodied nozzles with hardened stainless steel cores and orifices are probably the most satisfactory combination. All nozzles, however, must be periodically recalibrated or replaced to insure that pesticides are applied at the desired rate.

Another type of nozzle that needs consideration is used on the hoppers of granular applicators when applying granules in bands or rows. Though these devices are sometimes called spreaders or diffusers, they

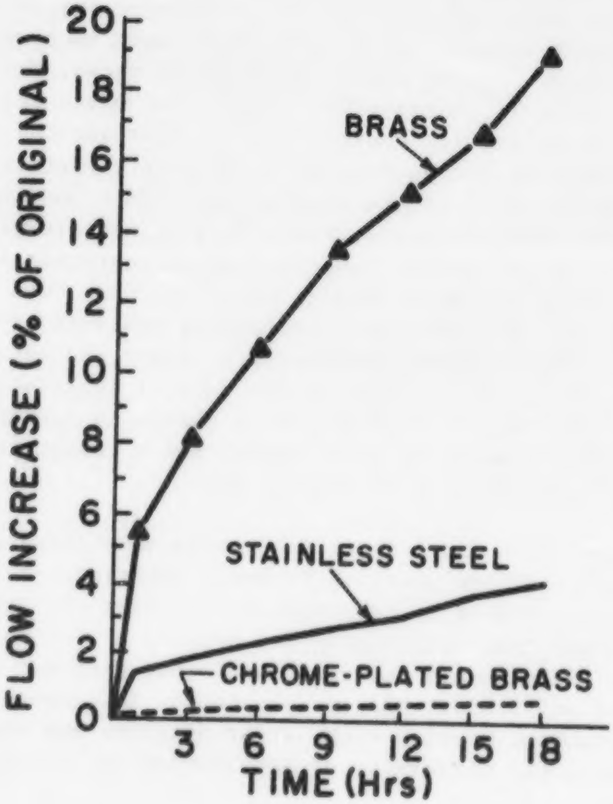

Figure 1. Flow increase due to nozzle wear, when spraying a typical wettable powder formulation.

Source: Beasley, E. D., and Glover, J. W., "Orchard Spray Equipment," North Carolina Agricultural Extension Service, Circular 501, January 1969.

are a type of nozzle used extensively in agriculture to dispense granules in band applications. The most common type used with granular applicators are fan shaped. Dispersion is obtained by baffle plates, splash pins, or perforated dividers within the fan. These nozzles are mounted over the discharge openings of the applicator to control the lateral direction of the granular pesticide flow.

Bands are typically 7 to 14 in. wide, and may be formed with a single fan or two fans fed from separate hopper discharge openings. The uniformity of distribution in a lateral direction is not much better than the uniformity of distribution in a forward direction. Experimental tests have shown that irregular lateral distribution patterns are formed, with the ratio of maximum to minimum discharge rates for 1-in. increments of width ranging from 2:1 to 5:1 (similar to the forward direction cyclic variations).[8] As a result of these irregularities, the problem of nonuniform distribution is enlarged when the lateral variations are superimposed upon the down-the-row variations, causing similar but magnified distortions in band applications compared to broadcast applications of granular products. The problems of nonuniform distribution and overapplication due to these effects that were discussed in the previous section apply to this situation as well.

Spray Tank Agitation - Liquid reservoir tanks used in spray application equipment are agitated mechanically or hydraulically. Mechnical agitation is normally done with a series of paddles on a shaft that runs horizontally through the tank or by a propeller at one end of the tank. Hydraulic agitation is accomplished by routing a portion of the pressurized spray liquid back into the bottom of the spray tank through a series of jet nozzles or orifices. Mechanical agitation is normally used for oil emulsions and wettable powders, whereas hydraulic agitation is commonly used for soluble or self-emulsifying solutions.

Agitation is necessary to keep the spray ingredients uniformly mixed, particularly in the case of wettable powders and oil emulsions, since these formulations may separate from water if allowed to stand. If separation does occur, the uniformity of application is adversely affected. Figure 2[9] shows how the application rate of a wettable powder is affected without agitation: the rate falls drastically with time as the solution separates. Therefore, it is important that such liquids be agitated during spraying. If the tank has no agitation system, an agitation system inadequate for the liquid being mixed, or an inoperable agitation system, then the uniformity of the pesticide distribution will be adversely affected. The operator may apply the proper volume of spray to his crop, but the amount of pesticide in the spray mixture applied without proper agitation will vary greatly with time.

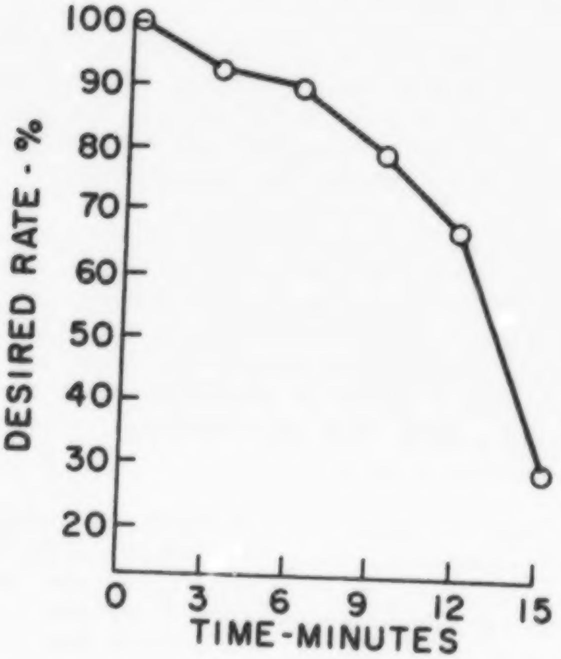

Figure 2. Decrease in application rate of a wettable powder with time, sprayed from a tank with no agitation.

Source: Beasley, E. D., and Glover, J. W., "Orchard Spray Equipment," North Carolina Agricultural Extension Service, Circular 501, January 1969.

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Operational Equipment Problems

The operation of the application equipment must be done properly to minimize nonuniform distribution and overapplication of the pesticide. Several factors critical to satisfactory application of the pesticide are: (a) equipment calibration; (b) proper forward speed of the unit; (c) proper height of the spray boom; (d) proper pesticide formulation; and (e) proper aircraft spray distribution. Each of these criteria of operation is discussed separately below.

Equipment Calibration - In order to insure the proper rate of application, all spray and granular applicators must be calibrated prior to operation. Manufacturers of equipment provide manuals and instructions giving the proper procedure to use, and since the types of equipment available are quite diverse, the details of calibration procedures cannot be discussed here. However, some of the problems associated with calibration of equipment are worth noting.

First, not all operators calibrate their equipment since some are unable or unwilling to follow the rather complicated procedures, preferring to rely on their own judgment and experience. Those farmers who follow these practices sometimes find that the first tankful of pesticide has been applied at an excessive rate, and belatedly adjust the rate of application for the next tank.

Second, the rate of application depends primarily on the nozzle size, nozzle spacing, discharge pressure (for sprays), and forward speed of travel. Once the nozzles are in place and the pressure has been set, the application rate depends upon the forward speed. If the speed of calibration is faster than the application speed, overapplication will result during crop treatment.

Third, many spray calibrations are made with water (which is often recommended by the manufacturer). This practice can cause difficulties because the viscosity or density of the pesticide formulation often varies from that of water; the application rate of the pesticide could be higher than that of the water. In these cases, the equipment should be rechecked or recalibrated with the pesticide at the beginning of crop treatment.

The same argument holds true for granular pesticides. Calibration must be performed for each granular formulation since the rate of application varies widely for granules of different sizes, shapes, and densities. Problems develop when the same application rate is desired for a different formulation than the one previously applied, and rather than recalibrate the equipment, the same setting is used. This generally results in an erroneous application rate.

Fourth, once the calibration has taken place, the nozzles, nozzle arrangements, pressures (for sprays), and formulations should not be changed without recalibration. If any of these factors change (i.e., a higher pressure is desired for good coverage), a risk of overapplication results if recalibration is not done. The tendency is not to recalibrate after application has begun, especially in cases where the farmer is operating on a tight schedule.

Finally, mathematical miscalculations can occur at the time of calibration, and the actual application rate be different from the calculated (intended) one. This results from human error, and is, to an indeterminate degree, inherent in the process.

Forward Speed of the Unit - During treatment the rate of pesticide application varies inversely (though not always proportionally) with the forward speed of the unit. To apply the chemical to the crop at a constant rate requires maintaining a constant speed. This, however, is difficult to do under certain conditions.

Overapplication occurs when the vehicle is operated slower than is required. This commonly occurs when operating on uphill slopes, turning around, or encountering obstacles. Many units can be shut off by the operator when encountering obstacles or turning around, and this practice is common, though not universal. However, on uphill slopes the crop must be treated, and unless a constant speed is maintained, overapplication will occur when the applicator slows down. Conversely, an excessive speed may cause underapplication and poor pest control, a result which may lead the farmer to overcompensate (by using higher application rates) the next year.

Height of the Spray Boom - Ground spray-application booms that hold the nozzles and dispense the pesticide must be operated at the proper height. Since nozzles are normally designed to dispense the pesticide at a high rate directly beneath, and at a lower rate at the periphery of the spray pattern, a 50% overlap between nozzle spray patterns is frequently used to provide uniform coverage. Once the nozzle spacings are fixed on the boom then, the height of the boom determines the distribution pattern.

Whenever using fan-spray, solid-cone, or hollow-cone nozzles, the distribution pattern of the spray is affected less by having the boom too high than by having it too low. High boom settings cause excessive overlap, while low boom settings cause insufficient overlap. Excessive overlap does not distort the spray application pattern as much as insufficient overlap.[8] Therefore, when the proper boom height is in doubt, it is better to have it too high than too low. Unfortunately, in considering drift, the reverse is true. In either case, however, the improper boom height will cause nonuniform distribution.

Improper Pesticide Formulation - Miscalculations on the part of the farmer, misinterpretations of the label recommendations, or improper measurements can cause the concentration of the mixed formulation to be in error. When the concentration is higher than that intended, overapplication will result. Occasionally this will occur as humans are subject to error. However, economics plays an important part in farm operations, and the cost-consciousness of farmers is a good deterrent to the use of improper formulations, and from this point of view, keeps overapplication at a minimum.

Aircraft Spray Distribution - Fixed-wing aircraft flying at low levels have wide variations in the spray deposit pattern on the ground beneath them Figures 3 through 5[10] show some examples of how the spray distribution from aircraft is nonuniformly distributed across the swath. In Figure 3 the nozzles are evenly spaced, while in Figure 4 the nozzles are both unevenly spaced and absent from the center of the boom. Figure 5 compares a coarse spray pattern and a medium spray pattern. Notice that in all cases the distribution is nonuniform.

Attempts have been made to overcome this problem and improve the uniformity of the spray distribution across the swath. Both irregular and asymmetrical spacings of nozzles, and combinations of nozzles across the boom producing coarse and fine sprays, have been tried with some success but the problem still exists. The spray pattern from a boom may be uniform in the laboratory, but when the boom is mounted on an airplane and subjected to crosswinds in the field, the pattern becomes distorted.

To add to the problem, the deposit pattern along the line of flight of the aircraft is irregular, also. Studies conducted on this subject have shown that the amount of spray deposited in high dosage areas is commonly four to five times greater than the amount deposited in low dosage areas.[11] Clearly, this represents a nonuniform distribution of pesticide sprays of large magnitude, considering the amount of aerial spray applications performed on crops each year. The problem, however, appears to be insolvable, since no nozzle arrangement or spacing can accommodate the many atmospheric disturbances that exist in actual field operations.

Quantification of Overapplication and Nonuniform Distribution

It should be apparent that the mechanisms which cause overapplication and nonuniform distribution discussed in this section defy quantification in the strict sense. The nonuniformity of distribution caused by metering devices, nozzles, and poor tank agitation have been studied and quantified in some cases, as previously discussed; however, to attempt to quantify factors such as the type of metering devices used, the

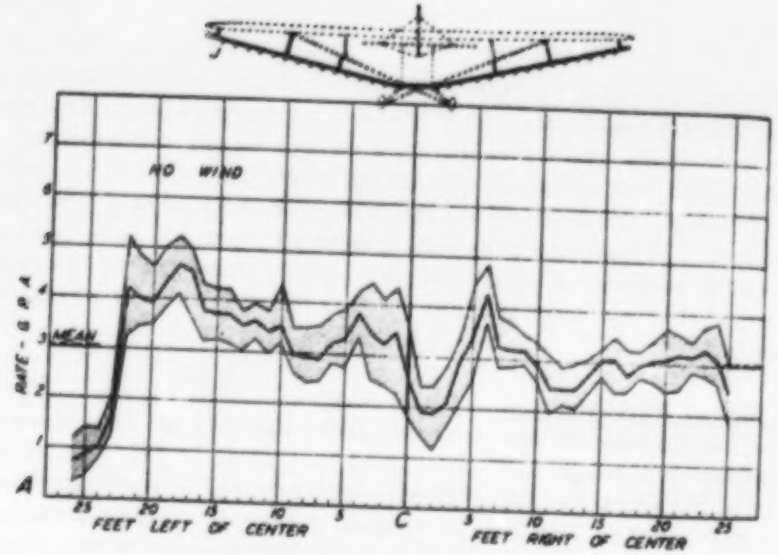

Figure 3. Spray distribution at a 2-ft flight level from evenly spaced nozzles on a high-wing monoplane.

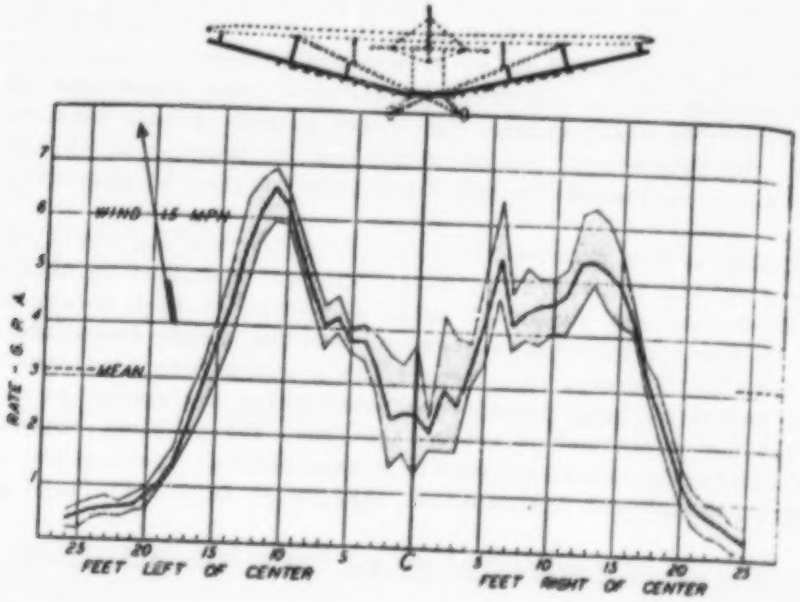

Figure 4. Spray distribution from unevenly arranged nozzles (none in the center boom section) on a high-wing monoplane at a 1- to 2-ft flight level.

Source: Chamberlin, J. C. et al., "Studies of Airplane Spray-Deposit Patterns at Low Flight Levels," USDA Technical Bulletin No. 1110, May 1955.

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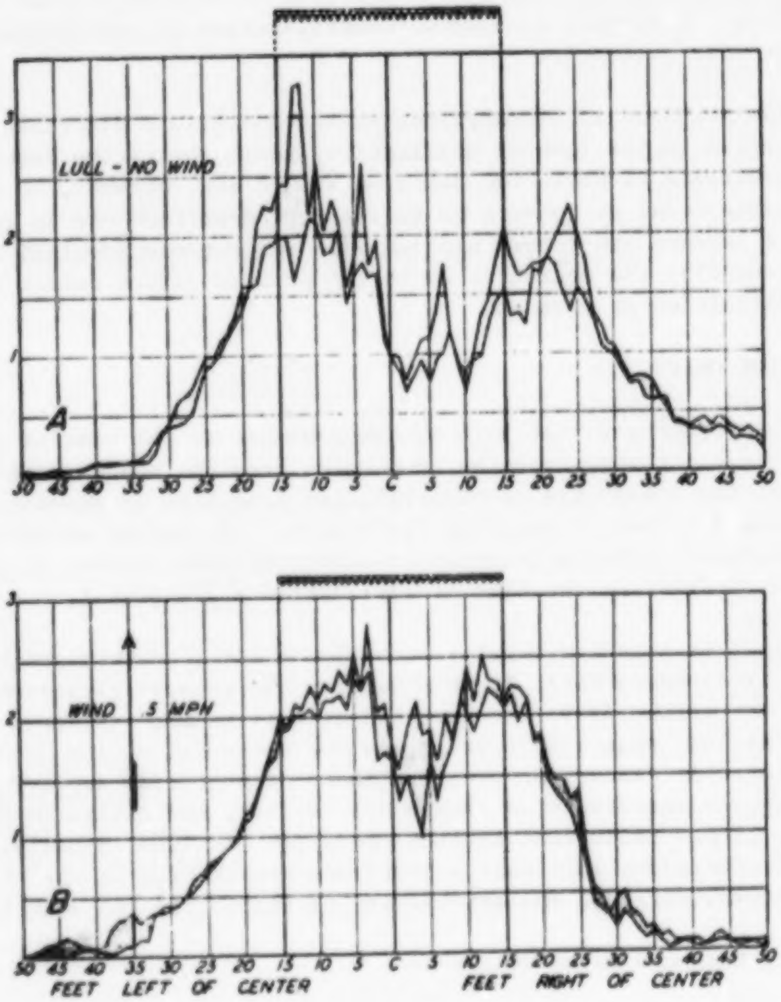

Figure 5. Spray-distribution curves for applications at a 2-ft flight level from 30 evenly spaced nozzles on a Stearman biplane: A, coarse spray; B, medium spray.

Source: Chamberlin, J. C. et al., "Studies of Airplane Spray-Deposit Patterns at Low Flight Levels," USDA Technical Bulletin No. 1110, May 1955.

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number of nozzles that clog or wear out during application, and the number of tanks that are improperly agitated would require time and data far beyond that presently available. Quantification of operational factors is even more difficult.

The problems of overapplication and nonuniform distribution, then, must remain in the form of qualitative, semiquantitative descriptions. The importance of these two problems should not, however, be considered negligible or of no concern to inefficient pesticide use in agriculture. It is a current and future problem with which those involved must deal. Unfortunately, the degree to which the problem exists defies more precise definition at present.

PESTICIDE DRIFT

Pesticides are lost into the environment at the time of application when they drift away from the crop being treated. Under certain circumstances, the losses are substantial, and pose both an immediate and long-term hazard to the surrounding environment. The extent of drift cannot be considered either accidental or uncontrollable. Losses of pesticide because of drift at the time of application are wasteful.

Drift is a rather complex mechanism which is determined by a variety of interrelated factors. In this section the general parameters and factors which affect drift are examined as well as more specific details on the parameters that affect drift and the potential of its occurrence. Following this discussion the likelihood of pesticide drift in various agricultural operations is examined in detail, and estimates of the percentage of pesticide lost in each operation is given. Finally, the quantities of pesticides lost during pesticide application to the three study crops--corn, sorghum, and apples--are estimated for the year 1971.

The sections which follow are:

1. General Drift Parameters;
2. Specific Drift Parameters;
3. Likelihood of Pesticide Drift in Agriculture; and
4. Estimated Pesticide Losses Due to Drift From the U.S. Corn, Sorghum, and Apple Crops (1971).

General Drift Parameters

Once a particle is released into the air during pesticide application, its movement is subject to both gravitational and aerodynamic drag forces in accordance with Newton's second law of motion: force = mass x acceleration. Drift, as defined for this discussion, originates when forces acting on the particle move it in the wrong direction, and the particle ends up in a location 1,000 ft or more from the target area. The basic parameters which influence the occurrence and extent of particle (or droplet) drift are the properties of the particle and the meteorological conditions to which it is subjected. Each of these parameters is discussed below.

Particle Properties - The most important property affecting the susceptibility of a particle in air to aerial transport is its size. Two other variables, density and shape, have a much lesser effect, but nonetheless must be taken into consideration once the particle size is given. These two lesser variables are discussed first.

Particle density - Particle density is determined by the density of the formulation. Solid formulations (dusts and granules) have a specific gravity greater than that of water, ranging from 1.3 to 3.0, with a typical value of 2.5. Liquid formulations have specific gravities ranging from 0.8 for oil carriers to 1.2 for some materials, with the typical value of 1.0 (since most applications use water as the carrier).[12] Specific gravities of less than 0.7 and greater than 1.3 are rarely encountered in liquid formulations.[13]

Density affects the rate at which particles fall in air due to gravitational forces. All other variables being equal, a particle with a higher density is less susceptible to drift than a lighter one. On the basis of density alone solid formulations are less susceptible to drift than are liquid ones. To minimize drift, then, a high density is desirable.

Particle shape - Particle shape affects the fall of the particle since aerodynamic drag forces acting against fall counteract the gravitational forces. As the particle accelerates toward the earth, the aerodynamic forces will eventually counterbalance the gravitational forces, and a constant (terminal) velocity will be reached. Drift susceptibility is reduced as the terminal velocity of a particle increases, since the time it remains airborne for a given distance of fall is reduced.

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Particles of an irregular shape have lower terminal velocities than spheres, although these effects are variable. (For example, a bullet-shaped particle would be better than a sphere.) If solid pesticides are formed in smooth spherical shapes rather than irregular ones, the drift is generally reduced. Liquids, on the other hand, assume different forms when dispersed into the air. Water droplets have similar terminal velocities to those of rigid spheres, and other liquids are deformed from aerodynamic forces and internal circulation.[13] In the case of liquids, high density, high surface tension, and low viscosity minimize drop deformation and, thus, increase the terminal velocity.[12]

Particle size - Although density and shape have an affect on the drift potential of particles, by far the most important particle property is its size. Agricultural pesticides are dispersed into the environment during crop treatment in sizes ranging from as little as 1 μ to over 2,000 μ. When the lesser effects of density and shape are equal for different particles, the drift potential increases greatly as particle size decreases.

Particle size is related to the type of formulation used. The formulations most commonly used in agriculture are dusts, granules, and sprays. Each of these formulations is examined separately.

Dusts - Particle size for dusts, as previously mentioned, is determined primarily by the manufacturer. Dust concentrates are normally screened to a range of 1 to 25 μ, with a stated average of 80 to 90% of the formulation below 25 μ.[1] The number median diameter, NMD (the median diameter that divides the formulation into two equal portions on the basis of the number of particles), ranges from 1 to 10 μ for most commercial dusts.[8] Field-strength dusts are prepared with particle sizes ranging from 30 to 50 μ.[2]

Granules - Granules are produced by impregnating, dry mixing, or adhesive binding a carrier with pesticide, and then carefully screening the particles to size. The size range is commonly 16/30 to 30/60 mesh (U.S. standard sieves*), making the granule size range from 1,190 to 250 μ.[8] Particles in this range, particularly the dense solid granular particles, are not subject to drift to any extent.

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* Note: The sieve opening sizes for 16-, 30-, and 60-mesh U.S. standard sieves are 1,190, 595, and 250 μ, respectively. A 30/60 size range means the screened material will pass through a 30-mesh screen but not through a 60-mesh screen.

Sprays - The sizing of spray droplets is not determined at the time of formulation, as with dusts and granules, but at the time of application. For this reason, spray droplet sizes vary widely from aerosols to globules. Many factors determine the size of droplets at the time they are dispensed into the environment. These factors not only determine the size of the particles, but their drift potential as well.

Before beginning the discussion on droplet size, the term volume median diameter (VMD) needs to be introduced. Since a spray is actually a spectrum of different size droplets, VMD is used to designate the average droplet size of the spray spectrum in terms of a median diameter. The VMD divides the droplet spectrum into two portions such that the total volume of all droplets smaller than the VMD is equal to the total volume of all droplets larger than the VMD.

The most important variables affecting the size of spray particles are: (a) nozzles--types, sizes, and orientation; (b) discharge pressure; (c) liquid properties--viscosity, vapor pressure, density, and surface tension; and (d) additives and formulations. The following discussion shows the relative importance and effect of each variable on particle size.

Nozzles - A wide variety of nozzles is available for spray applicators. The types of nozzles most commonly used on agricultural ground or aircraft equipment are fan, cone, jet, and flooding. The fan nozzles are most commonly used on ground equipment, but to a limited extent are also used on aircraft. Cone is the most common nozzle type mounted on aircraft. The flooding and jet nozzles are used on ground and aircraft equipment, respectively, to produce coarse spray droplets. Droplet size depends upon the discharge pressure, orifice size, nozzle orientation, and nozzle type. For common use the drop sizes produced by each type of nozzle are: fan and cone, 125 to 500 μ VMD; and jet and flooding, 600 to 1,000 μ VMD.[14]

Orifice size on the commonly used commercially available aerial spray nozzles ranges from 0.041 to 0.25 in.[15] For a given pressure, the droplet VMD increases as orifice size increases, though not proportionally. Doubling the area may increase the VMD by 10 to 30%.[8]

Orientation of the nozzle is important in aircraft spraying. On fixed wing aircraft, a nozzle pointed downward (vertical) produces a finer spray droplet size than when pointed back (with the airstream) for normal water diluted sprays. On helicopters, the reverse is true; that is, a nozzle pointed down (vertical) produces a coarser spray than one oriented at an angle to the vertical. To demonstrate this effect, Yates et al. (1964)[16] performed tests with an SSD6-46 (cone) nozzle oriented vertically and oriented back on agricultural dispersement equipment mounted on a modified Stearman aircraft. With the nozzle directed back, the droplet size produced was 420 µ VMD compared to 290 µ VMD with the nozzle directed down.

Discharge pressure - Nozzle discharge pressures can vary widely in agricultural pesticide applications. Aircraft, both fixed and rotary wing, can use liquid discharge pressures between 10 and 60 psi; ground rigs spraying the soil, or plants, can operate between 10 and 120 psi; and orchard sprayers use pressures up to 800 psi (for high volume spraying of 400 to 600 gal/acre). The effect of discharge pressure on spray droplet size is to increase the VMD as pressure decreases for a given hydraulic nozzle--though this relation varies from nozzle to nozzle, and data from various sources are inconsistent. Generally, a reduction in pressure of 50% in the range of 25 to 100 psi on a hollow cone or fan spray nozzle increases the VMD by about 10 to 30%. Other investigations have shown that with disc-type hollow cone nozzles at pressures above 100 psi, the VMD varies as the inverse square root of pressure.[8]

Liquid properties - The most important properties affecting the size of a droplet are: (a) density; (b) surface tension; (c) viscosity; and (d) vapor pressure. At the time the droplets are formed in agricultural spray systems, the first three properties affect the particle size, while vapor pressure has no appreciable effect. After the droplet is formed the vapor pressure predominates since it affects the rate of evaporation and, therefore, the change in the particle size with time.

Density has little effect on the droplet size produced in agricultural spraying since spray formulations have a small range of specific gravity (0.8 for oil carriers to 1.2 for other materials). The effect of density on droplet size formation in aircraft is to decrease the drop size as the liquid density increases. This relationship is caused primarily by the slipstream air effects.[1]

Surface tension is the force of a liquid that resists the formation of a new surface. When a droplet is first formed, the newly formed surface has a dynamic surface tension that changes with time. The droplet eventually reaches equilibrium and at this point the static surface tension is established, which is normally referred to as the "surface tension." It is the dynamic surface tension, i.e., that which evolves at the time of atomization, that should be used to predict drop size.[12] An increase in dynamic surface tension has been shown to increase the amounts of spray deposit, while at the same time increases the size of the drop in aircraft spray.[1]

Viscosity has an important and significant effect on the droplet size spectrum. A high viscosity reduces the proportion of small drops initially present in the spray emitted from any given nozzle,[13] thereby increasing the spray drop VMD. Also, once droplets are formed by aircraft, they are subject to secondary breakup which will increase the droplet spectrum, reducing the drop VMD. The higher the viscosity of the fluid, the less likely secondary breakup will occur since a higher viscosity delays drop disintegration, thereby increasing VMD.

At the time liquids are released by aircraft into the airstream, they are subjected to a high shear force. The viscosities of simple Newtonian fluids such as water, are unaffected by the shear rate, while the viscosities of complex, or non-Newtonian fluids are a function of shear rate. Many of the drift control agents developed recently to increase the viscosity of the liquid formulation are non-Newtonian fluids, and the shear rate has an important effect on their performance. The high shear rate at the time of release makes the apparent viscosity of liquids containing these control agents low (apparent viscosity decreases as shear rate increases) in the range of simple fluids that are normally used in spray formulations. Once the droplets are formed, there is very little secondary breakup since the apparent viscosity increases dramatically as the shear rate falls. However, the advantage of larger drop formation by the increased viscosity of the fluid containing the control agents is reduced if the nozzles produce a high shear rate on the film formed by the nozzle. Therefore, the type of nozzle critically affects the drop size distribution of high viscosity non-Newtonian fluids.[12]

Vapor pressure of the liquid has no apparent effect on the initial drop size spectrum of the common agricultural sprays.[12] However, once the droplets are formed and are dispersed into the air, vapor pressure has the most important effect on the size of a drop during its flight to the target, since the vapor pressure affects the rate of evaporation of the particle--the lower the vapor pressure, the lower the rate of evaporation.

The importance evaporation has on particle size, and, therefore, drift cannot be overemphasized. Since drop size is one of the most important parameters affecting drift, and evaporation directly affects the drop size with respect to time, the subject of evaporation will receive further consideration in the section on specific drift parameters.

Additives and formulations - Numerous additives and formulations have been developed to control the size of drops formed when spraying. The additives and formulations are employed to increase viscosity, increase surface tension, or lower the vapor pressure of the liquid formulations commonly used.

Additives are used to reduce evaporation and increase surface tension in water formulations. Tests show that a 30% (by weight) suspension of solids in water in an atmosphere of 104°F and 20% relative humidity results in drops of 150 μ becoming dusts while falling 20 ft. Under similar conditions, amine stearates added to the solution greatly reduce evaporation and 80 μ drops show no detectable evaporative loss during fall.[1] Long-chain fatty acids and salts of volatile bases incorporated into the spray liquid have also been shown to reduce the evaporation of falling drops.[13]

Spray viscosities can be modified (increased) by the use of thixotropic gel, hydroxyethyl cellulose, particulate sprays, and emulsions, both normal and invert. Emulsions of oil-in-water (normal) and water-in-oil (invert) are both used in agriculture today, while the other control agents have limited use. Liquid ratios in normal emulsions are usually 1:9, oil-in-water (O/W), while invert emulsions are at least 8:1, water-in-oil (W/O), and often higher.[1,13] Both types of emulsions increase the viscosity and reduce the evaporation of the formulation when compared to a simple, water-only formulation. Invert emulsions, however, reduce the evaporation substantially since water is the dispersed phase (surrounded by oil). Inverts have become more popular since the development of a Bi-Fluid Spray System, which permits satisfactory application of W/O emulsions in any desired phase ratio.[13]*

Meteorological Conditions - Pesticide particles released into the air during application are subject to drift from the target area as a direct result of aerial transport by atmospheric movement. Those meteorological conditions which most affect drift are: (a) wind direction and velocity; (b) turbulence; (c) relative humidity and air temperature; and (d) atmospheric stability. Each of these factors is examined below.

Wind direction and velocity - The direction the wind is blowing determines the direction of drift. Determining wind direction in the presence of adjacent crops or vegetation susceptible to damage by the pesticide in use is important in insuring that drift into the neighboring areas can be avoided.

Wind speed varies with different atmospheric stability conditions and imparts the lateral movement to particles in air. The average wind speed as well as the wind velocity gradient, are important in determining drift. The velocity gradient is the decrease in wind speed with height from the overhead boundary layer down to some point above the ground where the wind speed reaches zero. This profile varies with atmospheric stability and surface roughness and is important in trying to determine the effect of wind transport of particles near the ground surface. The potential for drift increases as wind speed increases.[12]

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* This is no longer true in the United States. The initial enthusiasm over invert emulsions has died out, since there are too many technical difficulties involved in their use and in their adaptability to normal spray techniques.

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Turbulence - Turbulence is a series of horizontal and vertical gusts and lulls, and random eddy movements of the air. It is dependent upon ground roughness, mean wind speed, and thermal stability of the air. Turbulence is one of the most important factors affecting drift since the combined forces of gravity, wind speed, and turbulence transport airborne particles.

Turbulence in a vertical direction is minimum under very stable atmospheric conditions (inversions), and consists mostly of horizontal eddy movements. Under unstable conditions vertical turbulence is maximized, and the upward projection of particles from vertical wind gusts makes the drift potential high. Therefore, common practice is to characterize the degree of turbulence and, therefore, the potential for drift, by referring to the stability ratio (S.R.), which is mathematically defined as:[16]

$$S.R. = \frac{T_2 - T_1}{\bar{u}^2} 10^5$$

where T_1 and T_2 are the temperatures, in °C, measured at 8 and 32 ft above the ground, respectively; and $\bar{u}$ is the mean horizontal wind velocity, in centimeters per second. The atmospheric conditions are classified into the following categories: very stable, S.R. greater than 1.2; stable, S.R. 0.1 to 1.2; nearly neutral, S.R. -0.1 to 0.1; and unstable, -0.1 or less. Therefore, when a high S.R. exists, drift potential is decreased under the stable conditions, whereas with a negative S.R., the drift potential is high under the unstable conditions.

Relative humidity and air temperatures - Relative humidity and air temperature can affect the rate of evaporation, and thus, the particle size of the liquid droplets. Both have an effect on water base drops, while only temperature affects nonaqueous liquid evaporation rates. A higher temperature increases evaporation rate, as does a lower humidity. The effect of temperature and relative humidity on water droplets is shown in Table 3,[17] which gives the lifetimes and approximate height through which three different sized drops would fall before complete extinction.

Table 3. LIFETIME AND FALL OF WATER DROPS THROUGH AIR

Initial diameter of drop (μ)	Ambient air conditions			
	20°C, 80% RH (ΔT = 2.2°C)		30°C, 50% RH (ΔT = 7.7°C)	
200	200 sec	268 ft	56 sec	69 ft
100	50 sec	22 ft	14 sec	6 ft
50	12.5 sec	5 in.	3.3 sec	1-1/4 in.

Source: Amsden, R. C., "Reducing the Evaporation of Sprays," International Agricultural Aviation Center, The Hague, Agricultural Aviation, 4:88.

Atmospheric stability - The stability ratio was previously defined and its magnitude indicates the degree of atmospheric stability. The very stable condition is known as an inversion, which occurs when the overhead layer of air is warmer than the air at ground level. This condition is characterized by low wind velocities, a small velocity gradient, and little or no vertical turbulence. On the other end of the spectrum is the unstable (lapse) condition which has a higher ground layer temperature than the overhead layer. This condition is characterized by high wind velocity, a large velocity gradient, and considerable vertical and horizontal air turbulence mixing. The intermediate (neutral) condition shows no change in temperature with height, milder winds, and milder turbulent conditions than does the unstable condition.

The conditions which predominate occur at different times of day. Neutral and lapse conditions prevail during the daytime when the sun is bright, while inversions occur during early morning hours, evening hours, and nighttime. On days when the sky is overcast, the temperature gradient will vary from an inversion to a neutral condition.[14]

Therefore, high turbulence is primarily a daytime phenomenon since turbulence is inversely related to the stability ratio. The drift potential of pesticides during application is lower under the stable conditions normally occurring in the morning or late evening hours, and, generally, these times are best for crop treatment with a minimum of drift.

Specific Drift Parameters

Briefly summarizing the previous section, we find that the most important factors determining the incidence of drift are: (a) particle size; and (b) wind speed and turbulence. This section deals with specific parameters affecting the quantity of drift involved at the time pesticides are released into the environment. The factors considered in this section, then, deal not only with the parameters just discussed, but with other important aspects of drift as well.

To quantify the amount of drift expected under various circumstances, a number of factors must be considered. They are:

1. Sedimentation and impaction;

2. Sedimentation and drift;

3. Impaction and drift;

4. Spray particle size spectrum;

5. Spray particle evaporation; and

6. Drift potential quantified.

This section concludes with estimates on the quantities of drift potential based upon the information presented here and in the previous section. These estimates are used extensively in the section "The Likelihood of Pesticide Drift in Agriculture."

Sedimentation and Impaction - The objective of applying any agricultural chemical is to place the chemical in the right place and in the right form. Pesticides applied to crops have one of two basic targets--the crop soil or the crop plants. When the pesticides are released, there are several ways by which the particles or droplets are collected on the intended target. They are:

1. Sedimentation upon horizontal surfaces;

2. Impaction upon vertical surfaces;

3. Interception; and

4. Attractive electric forces.

Sedimentation and impaction are by far the most important mechanisms of particle deposit, and are the only mechanisms considered here. Interception (in which the trajectory of a particle is such that the center misses the obstacle, but, because of its finite size, the particle nonetheless comes into contact with the obstacle, and is collected) becomes appreciable when the target and particle are of comparable size, such as when contact insecticides are used on insects.[18] Since the concern here is with pesticides applied to soils or plants, the effect is negligible. Attractive forces are small also unless an electrostatic charge is put on the particles (as is sometimes done in dust applications).

Sedimentation is simply the settling of a particle in the air onto a horizontal surface, usually the soil. Pesticides released into the air, whether from a height of 6 in. or 20 ft, are attracted by gravitational forces and settle toward the earth. They accelerate until they reach a constant velocity known as the terminal velocity. Particle resistance to drift is directly related to this terminal velocity since the time the particle remains in the air is dependent upon this velocity. As terminal velocity increases, the drift potential decreases.

Impaction is the collection of a particle carried in an airstream upon the vertical surface of an object. Pesticides released into the air are subject to diversion from their vertical path towards the earth by horizontal movement, whether caused by wind or by intentionally projecting the particles in a certain direction (as when spraying). The particles tend to follow a divergent flow around the target and not to impact. The degree to which impaction occurs is referred to as the impaction efficiency, expressed as a percent of the particles collected to those that would have collected on the object had they not been deflected from their original course.

Sedimentation and impaction are now considered with relation to particle size to determine the effect this size has on these two mechanisms, and ultimately, the effect on the drift potential.

Sedimentation and Drift - Sedimentation is important since many pesticides are released above the target obstacle and will not be deposited on the intended surface unless sedimentation takes place. The dominant factor determining the fall of particles in air is their size. Table 4[12] shows the effect of particle size on the terminal velocities of rigid spheres (sp. gr. = 1.0), heavier rigid spheres (sp. gr. = 2.5), and water droplets (sp. gr. = 1.0).

This table shows that the terminal velocity of particles increases with size and density, and that water droplets behave similar to solid particles. Solid agricultural pesticides have a typical specific gravity of 2.5 and agricultural sprays (mostly water diluted) have a typical specific gravity of 1.0. The terminal velocities shown in the table then, apply to the pesticides used in agriculture.

The particle size most critical for sedimentation to take place without drifting is dependent upon the height of release above the target surface, the particle density, and the wind speed and turbulence. Release height can vary from 20 ft to 6 in., depending upon the application method. The wind speed varies in a wide range, but will normally be below 10 mph during pesticide application, and is assumed to have an average value of 3 to 5 mph. Turbulence varies with the stability ratio and is quite unpredictable. However, we will assume relatively low turbulence accompanies the typical wind speeds used.

The effect terminal velocity has on falling particles and their drift potential is shown more clearly by Tables 5 and 6. Each table shows the amount of time it takes particles of various sizes with a given specific gravity to fall a certain distance. The longer a particle takes to fall, the more susceptible it is to drift from varying wind speeds and turbulence. These tables assume no turbulence.

Table 4. TERMINAL VELOCITIES OF PARTICLES IN AIR

Diameter (μ)	Rigid sphere (sp. gr. = 1.0) (ft/sec)	Rigid sphere (sp. gr. = 2.5) (ft/sec)	Water droplet (sp. gr. = 1.0) (ft/sec)
1	0.00011	0.00028	0.0001
10	0.01	0.025	0.01
50	0.25	0.63	0.25
100	0.85	1.8	0.89
200	2.4	4.6	2.4
300	3.9	7.5	3.8
400	5.3	10.0	5.3
500	6.8	12.5	6.8
1,000	13.3	23.0	13.2

Source: Yates, W. E., and Akesson, N. B., "Reducing Pesticide Chemical Drift," Pesticide Formulations, Marcel Dekker, Inc., New York, p. 282 (1973).

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Table 5. TIME REQUIRED FOR A SOLID PARTICLE TO FALL A GIVEN DISTANCE[a/]
(sp. gr. = 2.5)

Particle diameter (μ)	Release height (ft) 0.5	1.5	3	10	20
1	30 min	90 min	180 min	600 min	1,200 min
10	20 sec	1 min	2 min	6.7 min	13.4 min
50	0.8 sec	2.4 sec	4.8 sec	16 sec	32 sec
100	0.3 sec	1 sec	2 sec	5.6 sec	11.1 sec

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a/ Assumes no turbulence.

Table 6. TIME REQUIRED FOR A PARTICLE TO FALL A GIVEN DISTANCE[a/]
(sp. gr. = 1.0)

Particle diameter (μ)	Release height (ft) 0.5	1.5	3	10	20
1	75 min	226 min	450 min	1,515 min	3,030 min
10	50 sec	2-1/2 min	5 min	16.7 min	33.3 min
50	2 sec	6 sec	12 sec	40 sec	1.3 min
100	0.6 sec	1.7 sec	3.5 sec	11.6 sec	23 sec

---

a/ Assumes no turbulence.

Considering that 10 sec in the air allows particles enough time to become subject to the vagaries of wind turbulence and speed, the lines show those small particles which remain above the target approximately 10 sec or more after release. Therefore, the particle size below which the drift potential is very high is 50 μ for aircraft (typical release height 5 to 20 ft) and 10 to 20 μ for ground equipment. Larger sized particles also have drift potential, but this potential decreases rapidly with size. At 100 μ the drift potential for ground applications is virtually nil, and for aerial applications it is also very small.

Further evidence is presented to show that the particle sizes above are reasonable values:

1. Hartley (1959)[18/] reported that particles under 50 μ diameter "just make it" (to the ground) in upward winds (turbulence) of 1/6 mph.

2. Yates and Akesson (1973)[12/] reported that the distance required for a water drop to reach its terminal velocity when falling in air is less than 1 in. for particles less than 100 μ, 2 ft for 500 μ particles, and 15 ft for 2,000 μ particles.

3. Table 7 shows the lateral distance particles will drift when released from both a 20 ft and a 10 ft height in wind speeds of 5 and 3 mph, respectively, and no turbulence.

In summary, the evidence presented here shows that a particle whose size is less than 50 μ has a very high drift potential in aerial applications, while a particle whose size is 20 μ or less has a very high drift potential when released at a height of 3 ft or lower by ground equipment.

Impaction and Drift - Impaction depends not only upon the particle size but the speed at which it approaches an object and the size of the object as well. Figure 6 shows in graphical form a study by R. T. Jarman (1957).[6/] This figure shows that: (a) as wind speed decreases, impaction efficiency decreases; (b) as object size increases, impaction efficiency decreases; and (c) as particle size decreases, impaction efficiency decreases.

This fact was further demonstrated by F. A. Brooks (1947)[8/] and is illustrated in Figure 7. This figure shows percent impaction efficiency (called percent catch here) for droplets 100 μ and less at wind speeds up to 100 mph. Forty micron droplets do not reach 100% efficiency at speeds less than 100 mph.

Table 7. THEORETICAL DISTANCE SOLID PARTICLE WOULD DRIFT IN 5 AND 3 MPH WINDS FROM A HEIGHT OF 20 AND 10 FT, RESPECTIVELY[a]

Drop diameter (μ)	(20 ft, 5 mph)[b]	(10 ft, 3 mph)[c]
1,000	11.0 ft	(Not given)
500	21.6 ft	(Not given)
400	(Not given)	8.5 ft
100	172.0 ft	48.0 ft
50	587.0 ft	178.0 ft
10	253.0 miles	.84 miles

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[a] Assumes no turbulence.

[b] Source: Ref. 12.

[c] Source: Ref. 1.

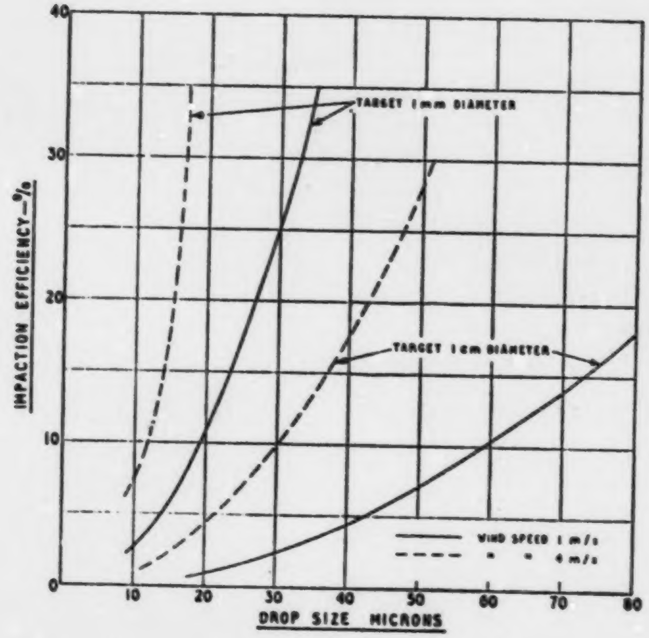

Figure 6. Efficiency of impaction of small droplets upon cylinders at speeds of 1 and 4 m/sec.

Source: Courshee, R. J., "Some Aspects of the Application of Pesticides," American Review of Entomology, 5:339 (1960).

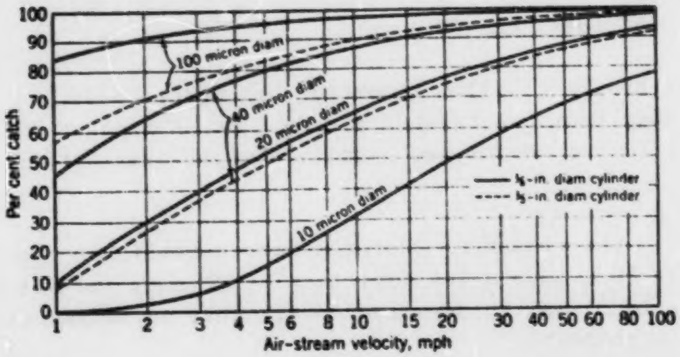

Figure 7. Effect of droplet size and velocity of approach upon the dynamic catch of two sizes of cylinders.

Source: Principles of Farm Machinery, Second Edition, The AVI Publishing Company, Inc., p. 273 (1972).

Since we have already assumed that typical wind speeds of 3 to 5 mph are experienced in agricultural pesticide applications, a table showing the impaction efficiencies and drift potential of particles is constructed in Table 8. This table assumes an object size of 1/2 in. diameter (such as a twig), and combines the data on the two graphs (which conflict somewhat). The table demonstrates that particles 40 μ and below have very high drift potential, while those 100 μ and above are much less susceptible to drift.

Further evidence of the low impaction efficiency is found in the literature and is presented here:

1. Splinter (1955)[6] reported that failure to impact occurs with particle sizes of less than 30 μ.

2. F. A. Brooks (1955)[8] reported that tests conducted with dusts showed drift away from the treated area may be as high as 70% of the total applied. (Note: dusts are particles whose diameter is less than 50 μ.)

In summary, the evidence presented here establishes the fact that particles below 50 μ have a low impaction efficiency and are highly subject to drift. Combining this evidence with that on sedimentation gives the following statements:

- All solid particles having a particle size of less than 50 μ have a greater than 80% chance of drifting 1,000 ft or more in 3 to 5 mph winds when applied by aircraft flying at 10 to 20 ft over the target.

- All solid particles having a particle size less than 20 μ have a greater than 80% chance of drifting 1,000 ft or more in 3 to 5 mph winds when applied by ground equipment from a height of 1.5 to 3.0 ft above the ground.

Up to this point only the size of an individual particle is considered. This applies to solids and liquids as well, but two other very important factors affect the particle size of liquids. The first is the fact that all spray patterns have a range of particle sizes, or a spray particle size spectrum. Once this spectrum of particles is released into the air, the particles are subject to a decrease in size through the mechanism of evaporation. Each of these important subjects is considered next.

Table 8. IMPACTION EFFICIENCIES AND DRIFT POTENTIAL OF PARTICLES IN 3 TO 5 MPH WINDS ON A 1/2-IN. CYLINDER

Particle diameter (μ)	Impaction efficiency (%)	Drift potential
10	< 10%	> 90%
20	< 10%	> 90%
40	10-40%	60-90%
100	80%	20%

Note: Drift potential is the opposite of impaction efficiency. The particles which do not impact are those that drift.

Spray Particle Size Spectrum - The range of droplet sizes from a nozzle under a given set of conditions is known as the droplet spectrum. The spectrum is more important than the VMD size, since the drift potential of a certain spray VMD is dependent upon the volume of small particles produced. Although this subject has been studied intensively, no current technology exists which will produce a single drop size from any nozzle, and most nozzles, in fact, have a very wide range of droplet sizes.

Table 9[14/] shows the drop size distribution by volume of selected drop size VMD's. These distributions are for aerially applied water-base sprays commonly used in agriculture. Sprays using different liquids can vary from the percentages shown there. An oil base spray will normally have a smaller percent of small droplets than water, since the viscosity is higher. Table 10[19/] shows the size distribution of an oil sprayed from a fern-type nozzle at 45 psi.

Notice that the VMD for the oil in Table 10 is in the 161 to 220 μ range (approximately 190 μ), and that the percentage by volume of droplets less than 100 μ is 7.34%, whereas, Table 9 shows that water base sprays with a VMD of 130 and 278 μ have 15.8 and 6.0% of the volume in droplets below 100 μ, respectively. The two types of sprays, then, have comparable values, and Table 9 is referred to in most cases when discussing the drop size spectrum of a given VMD.

Water-in-oil (invert) emulsions and oil-in-water (normal) emulsions display similar spectrums to those of water-base sprays. A study[13/] of the spectrums provided by a typical emulsion produced the information given in Table 11. This table shows that emulsions having VMD's of about 900 μ have droplets less than 200 μ in the range of 1.0 to 2.5% by volume. Table 9 shows that water sprays with a 900 μ VMD have a typical drop distribution of 5.0% by volume less than 220 to 240 μ. Emulsions, then, produce slightly fewer small drops than water-base sprays, but not appreciably so. (Note: The distribution values of the water base sprays in Table 11 are in good agreement with those in Table 9.)

In order to later quantify the likelihood of drift in agricultural operations, it is useful to introduce the nozzles and their spray distribution patterns provided by a large nozzle manufacturer, Spraying Systems Company. Literature[15,20/] provided by this company shows the nozzles commercially available, rates of application, the droplet sizes each nozzle produces at various pressures, and the spray distribution pattern of each nozzle under laboratory conditions. This information is summarized in Table 12, showing typical nozzles and application rates used in agriculture. The associated drop VMD's, and percent of small particles produced under laboratory conditions are shown with each type of operation at the given pressure.

Table 9. DROP SIZE DISTRIBUTION (CUMULATIVE PERCENT BY VOLUME BELOW SIZES SHOWN)

Drop size µm microns	< 50 µm Fine aerosols	50 to 100 µm Coarse aerosols	100 to 250 µm Fine sprays	250 to 400 µm Medium sprays	400 to 500 µm Coarse sprays	> 500 µm Very coarse sprays
1 to 5	5	0.1				
5 to 10	45	0.4	0.1			
11 µm vmd	50%					
10 to 15	77	2.0				
15 to 20	97		2.			
20 to 40	100	12.0		0.1		
40 to 60		35.0	5.	2.	0.01	0.001
60 to 80						
86 µm vmd		50%				
80 to 100		59.0	15.8	6.0	0.1	
100 to 120						
120 to 140					0.4	0.1
130 µm vmd			50%			
140 to 180		100.				
180 to 200			81.0	17.0	3.0	
200 to 220						
220 to 240					7.0	5.0
240 to 260						
260 to 280						
280 to 300			100.0	46.0	14.0	
278 µm vmd				50%		
300 to 350					24.0	
350 to 400					36.0	15.0
400 to 450					46.0	
460 µm vmd					50%	
450 to 500				92.0	55.0	
500 to 600					74.0	25.0
600 to 700					88.0	
700 to 800					96.0	
900 µm vmd						50%
800 to 1,000				100.0	100.0	100.00
vmd Nozzle Type	11 µm Cold Fogger 5 lb/in^2 Air	86 µm 2-fluid 30 lb/in^2 Air No air-stream	130 µm Spinner 90 to 100 mph Air	278 µm 65015 Fan Down 40 lb/in^2 90 to 100 mph Air	460 µm D6-46 Cone Back 50 lb/in^2 90 to 100 mph Air	900 µm D6-Jet Back 40 lb/in^2 90 to 100 mph Air

The vmd or volume median diameter is that size of drop which divides the total volume of drops found exactly in half. That is 50% of the volume is in drops above that size and 50% are below the vmd size. The size is measured in micrometers abbreviated to µm and frequently called microns. 25,400 µm equals 1 in.

Source: Akesson, N. B., and Yates, W. E., "Physical Parameters Relating to Pesticide Application," Personal Communication.

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Table 10. DROPLET SIZE DISTRIBUTION OF OIL DROPLETS SPRAYED FROM A FERN-TYPE NOZZLE

Droplet diameter (μ)	Droplets by volume (%)
10 to 40	0.14
41 to 100	7.2
101 to 160	27.2
161 to 220	35.9
221 to 280	10.7
281 to 340	18.5

Source: Edwards, C. J., and Ripper, W. E., "Droplet Size, Rates of Application and the Avoidance of Spray Drift, Proceedings of the British Weed Control Conference, p. 350 (1953).

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Table 11. VARIATION OF DROPLET SIZE WITH NOZZLE TYPE AND PHASE RATIO OF O/W AND W/O EMULSIONS

Nozzle type	Emission rate (gal/min)	Emulsion	Phase-ratio water/oil	Droplet VMD (µ)	Volume of droplets (%) < 200 µ
Ceramic V-jet (Allman 12)	0.6	w/o	13:1	1,620	0.2
	0.6	w/o	9:1	1,480	0.5
	0.5	w/o	6:1	1,300	1.0
	0.6	o/w	8:1	630	3.0
Ceramic V-jet (Allman 6)	0.5	w/o	10:1	840	0.6
	0.5	w/o	8.5:1	950	1.6
	0.5	w/o	6:1	700	1.6
	0.5	o/w	10:1	490	5.2
	0.5	o/w	5.5:1	360	12.0
V-jet (Spraying systems 5010)	0.6	w/o	12:1	1,280	0.2
	0.6	w/o	7:1	925	2.5
	0.5	water	-	515	5.8
Hollow cone (Watson WG 4008)	0.3	w/o	9:1	1,200	0.5
	0.3	w/o	4:1	870	1.0
	0.4	water	-	420	10.0
	0.3	water	-	370	8.6

Source: Coulthurst, J. P., et al., "Water-in-Oil Emulsions and the Control of Spray Drift," Symposium on the Formulation of Pesticides, S.C.I. Monograph No. 21, Society of Chemical Industry (1966).

Table 12. VARIOUS NOZZLES, DROPLET SIZE VMD'S, AND SPRAY DISTRIBUTION PATTERNS FORMED UNDER LABORATORY CONDITIONS AT STATED PRESSURES

Nozzle	Type	Use[a]	Gallons per acre[b]	Pressure (psi)	Drop VMD (μ)	Volume % less than the specified size (μ)
D2-23	Disc-type hollow cone	Helicoptor	0.59	50	200	7.5% < 120
D5-23	Disc-type hollow cone	Helicoptor	1.1	50	255	3.0% < 120
D5-25	Disc-type hollow cone	Helicoptor	2.1	50	300	2.5% < 120
D10-45	Disc-type hollow cone	Helicoptor	6.6	50	470	1.0% < 120
D2-23	Disc-type hollow cone	Airplane	0.25	50	200	7.5% < 120
D5-45	Disc-type hollow cone	Airplane	1.0	50	270	1.5% < 120
D10-45	Disc-type hollow cone	Airplane	2.8	50	390	0.5% < 120
9502E	95° Flat fan	Ground, band	7.4	40	375	0% < 100
9510E	95° Flat fan	Ground, band	37.0	40	575	0% < 100
9202E	95° Flat fan	Ground, broadcast	21.0	40	375	0% < 100
9504E	95° Flat fan	Ground, broadcast	42.0	40	420	0% < 100
8003	80° Flat fan	Ground, broadcast	16.0	20	430	0% < 100
8003	80° Flat fan	Ground, broadcast	22.0	40	390	0% < 100
8006	80° Flat fan	Ground, broadcast	31.0	20	550	0% < 100
D1-13	Disc-type hollow cone	Ground, plants	2.0	50	150	15.0% < 100
D2-13	Disc-type hollow cone	Ground, plants	3.5	50	170	9.0% < 100
D3-45	Disc-type hollow cone	Ground, plants	9.0	50	260	2.0% < 100
D10-25	Disc-type hollow cone	Ground, plants	40.0	50	410	0.5% < 100

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[a] Ground refers to applications made by ground equipment; band and broadcast are soil applications; and plants are foliar applications.

[b] Helicoptor with 45 mph speed, 45 ft swath, 22 nozzles; ground band with 4 mph speed, 14 in. band, height 7 in., 40 in. nozzle spacing; ground broadcast at 4 mph, any nozzle spacing; ground plant, 4 mph, one nozzle/row, 40 in. row spacing; airplane at 90 mph, 60 ft swath width, 24 nozzles.

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All of the information given in Table 12 is pertinent to the discussion on agricultural drift. The information in this table is used to show the droplet VMD produced with typical agricultural ground equipment. The statistics in Table 12 do not take into account the effects of wind speed and shear in aircraft operations so that the values of the droplet spectrum distribution percentages given are slightly low. The droplet VMD values are approximately correct (slightly low, also) and are used henceforth. Where the percentage drop-size spectrum below 120 μ in Table 12 disagrees with that given in Table 9 for a given droplet VMD, the value in Table 9 is used. (Table 9 shows the percentage drop size distribution by volume for aircraft operations.)

Tables 9 and 12 are nqw used to construct Table 13, which shows the droplet size VMD's and droplet size spectrums produced in typical agricultural operations. The importance of this table is apparent in a subsequent section when drift and VMD sizes are correlated.

The percentage of small droplets in a given drop VMD must be correlated with evaporation to determine the drift potential for sprays.

Spray Particle Evaporation - The drop spectrum produced at the nozzle is not the same as that arriving (or not arriving) at the target due to evaporation. The effect of evaporation in relation to particle size is a very steep variation in the life of a drop of volatile liquid with its initial size. Under standard conditions the decrease of a droplet's surface area by evaporation is approximately constant so that the reduction in volume is inversely proportional to the square of the diameter. This means that a 100 μ drop will evaporate to dryness in one-fourth the time a 200 μ drop evaporates.[18]

Evaporation effects on the lifetime and distance of fall before extinction of a water droplet are shown in Table 3 (p. 40). This table shows that when the relative humidity is 50%, or lower, and the temperature is 60°F or higher, a 100 μ particle released from an airplane (over 7 ft above the ground) will evaporate to dryness before sedimentation takes place. This effect is illustrated graphically in Figure 8.[21] This graph illustrates that 120 μ particles released from a height of 7 ft or more will completely evaporate and that 150 μ articles will evaporate to dryness at a height of 15 ft or more.

These two illustrations show the importance of evaporation on particle size. Using the data presented here, and in Table 6 (p. 45), which shows the time required for a given size particle to fall a given distance, Table 14 is constructed to show the size of a particle at the time of emission which will evaporate to less than 50 μ for aerial applications and to less than 20 μ for ground applications. As previously stated, particles below these sizes are highly subject to drift.

Table 13. WATER DROPLET SIZE VMD'S AND DROPLET SPECTRUMS PRODUCED IN CERTAIN AGRICULTURAL OPERATIONS AS A FUNCTION OF NOZZLE TYPE, PRESSURE, AND APPLICATION RATE

Application equipment	Nozzle type	Gallons per acre	Volume[a]	Pressure (psi)	Drop VMD (μ)	Drop spectrum volume % less than the specified size (μ)
Helicoptor	Cone	0.6-1.0	ULV	50	200-250	10% < 120
	Cone	1-5	LV	50	250-500	5% < 120
Airplane	Cone	0.2-1.0	ULV	50	200-250	10% < 120
	Cone	1-5	LV	50	250-500	5% < 120
Ground boom (band)	95° Flat fan	10-40	LV	40	350-600	0% < 100
Ground boom (broadcast)	Flat fan	< 10	ULV	30	300-400[b]	0% < 100
	Flat fan	10-40	LV	40	350-600	0% < 100
Ground boom (plants)	Cone	3.5	ULV	50	150-200	5-15% < 100
	Cone	10-40	LV	50	250-400	0.5-2.0% < 100

Note: Pressures of 50 psi are a little high for airplanes and ground booms (30-40 psi normal), but were the only pressures at which the information was available.

[a] LV = low volume, ULV = ultra-low volume.
[b] Estimated.

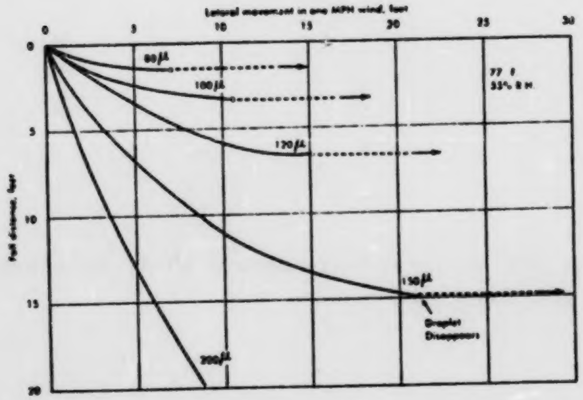

Figure 8. Evaporation rate of water droplets.

Source: Bowers, Wendell, "Reducing Drift of Spray Droplets," OSU Extension Facts, No. 1203.

Table 14. SPRAY PARTICLES SIZES AT EMISSION THAT DRIFT DUE TO EVAPORATION[a]

Emission diameter (µ)	Release height (ft)				
	0.5	1.5	3.0	10	20
10	X	X	X	X	X
50	X	X	X	X	X
80		X	X	X	X
100				X	X
120				X	X
150					X

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a/ Relative humidity, 50% or less; temperature 60°F, or above; wind speed, 3 to 5 mph; low turbulence.

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Since the most common types of formulations used in agricultural sprays are wettable powders, liquid concentrates, and emulsifiable concentrates, evaporation must be taken into account. Wettable powders are solid dusts that are suspended in water. Liquid concentrates are soluble, or emulsifiable to the point of being a solution in water, also. Emulsifiable concentrates, which are liquid organic solutions containing the pesticide, are emulsified into water. All of these formulations use water as the carrier, and when the water evaporates, all that remains is the pesticide dust or concentrate itself. (If the concentrate is volatile, it will undergo evaporation, also.)

Clearly, then, the process of evaporation that takes place after a droplet is emitted reduces its size and, consequently, increases the likelihood of drift for that drop. To summarize Table 14, the following statements apply to the particle size and drift of sprays:

- All pesticide droplets in water carriers having an initial droplet size less than 120 μ have a greater than 50% chance of drifting 1,000 ft or more in 3 to 5 mph winds when applied by aircraft flying 10 ft or more above the ground.
- All pesticide droplets in water carriers having an initial droplet size less than 80 μ have a greater than 50% chance of drifting 1,000 ft or more in 3 to 5 mph winds when sprayed from ground equipment from a height of 3.0 ft above the ground.
- All pesticide droplets in water carriers having an initial droplet size less than 50 μ have a greater than 50% chance of drifting 1,000 ft or more in 3 to 5 mph winds when sprayed from ground equipment from a height of 6 in. above the ground.

What remains now is to combine the information presented to this point into a table showing the relationship of particle size, release height, and drift potential. This is done in the next section.

Drift Potential Quantified - To this point both solid formulations and liquid formulations have been discussed. In quantifying the drift potential for liquids it is necessary to take into account evaporation and the spray drop spectrum, while for solids it is unnecessary. For convenience and clarity solid formulations and liquid formulations are discussed separately below.

Solid formulations - Agricultural pesticides are formulated both as dusts and granules. The drift potential encountered when treating crops with these solids is now summarized to show drift potential as a function of particle size and height of release, since both formulations may be applied with ground equipment or aircraft.

Using the information presented in Tables 4, 5, 7, and 8 on the preceding pages, Table 15 is constructed to show the drift potential of solids as a function of particle size and height of release at wind speeds of 3 to 5 mph, and neutral atmospheric stability. Table 15 will be used in all future estimates on drift quantities experienced during crop treatment with dusts or granules.

Spray formulations - In order to quantify the drift potential of individual spray droplets on the basis of initial size at the time of emission, evaporation is considered since this decreases the particle size as the droplet falls. In the case of small droplets (< 50 μ) the effect is appreciable since they both evaporate faster and have lower terminal velocities causing them to remain in the air longer.

The process of quantifying drift is done in two steps. First, the individual particle sizes are examined for drift potential with respect to initial particle size, height of release, and evaporation effects. The information in Tables 3, 6, 7, 14, and 15 on the preceding pages, and Figure 8 (p. 59) is used to construct Table 16. This table takes evaporation into account, and the first three drop size VMD's are similar to solids, since in this range they evaporate quickly. The 60-, 100-, and 120-μ sizes evaporate to dryness before sedimentation at the 10- and 20-ft heights. The 60-μ size evaporates to dryness at the 3-ft height before sedimentation. All other sizes at the associated release heights undergo some evaporation, but very little in the low release heights and large drop sizes. In the first 3 ft of fall, very little evaporation takes place at 100 μ and above. This is why the drift potential falls rapidly in the 0.5 to 3.0 ft range as size increases beyond 60 μ. The same reasoning holds for the large decrease in drift potential from 120 to 200 μ at 10 and 20 ft. Evaporation effects are almost negligible for the 200 μ droplet size at these heights.

Second, Table 17 is constructed from Tables 16, 13, and 9 on the preceding pages. The drift potential for each VMD range is approximated based upon the percentage of particles found in the particle size ranges indicated. The drift potential associated with aircraft producing sprays in each size range is given.

Table 15. DRIFT POTENTIAL AS A FUNCTION OF SOLID PARTICLE SIZE AND HEIGHT OF RELEASE AT GIVEN METEOROLOGICAL CONDITIONS[a]

Particle size (μ)	Drift potential (%)[b] Height of release (ft) 0.5	1.5	3.0	10	20
1	95+	95+	95+	95+	95+
10	80	85	95+	95+	95+
50	10	20	40	80	90
100	0	0	0	10	20
200	0	0	0	0	0

---

[a] Wind speed at 3 to 5 mph, and neutral atmospheric stability.

[b] Drift refers to a distance of 1,000 ft or more from the target area.

Table 16. DRIFT POTENTIAL AS A FUNCTION OF INITIAL DROP SIZE, HEIGHT OF RELEASE, AND EVAPORATION[a]

Initial drop size at emission (μ)	Drift potential (%)[b] Height of release (ft) 0.5	1.5	3	10	20
10	80	85	95+	95+	95+
20	80	85	95+	95+	95+
40	80	85	95+	95+	95+
60	40	60	70	95	95+
100	0	10	20	60	85
120	0	0	10	50	80
200	0	0	0	15	30

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[a] Wind speed 3 to 5 mph, and neutral atmospheric stability.

[b] Drift refers to a distance of 1,000 ft or more from the target area.

Table 17. ESTIMATED DRIFT POTENTIAL OF AIRCRAFT SPRAY AS A FUNCTION OF SPRAY DROP VMD AT EMISSION AND HEIGHT OF RELEASE[a]

Spray drop range VMD (μ)	Average volume[b] % below 100 μ	Average volume[b] % below 100 and 200 μ	Total volume % below 200 μ	% Drift potential[c] Height of release 10 ft	20 ft
50	100	0	100	80	90
50-100	60	40	100	65	75
100-200	20	50	70	35	50
200-250	10	30	40	20	30
250-400	3	5	8	10	15
400-500	0.1	3	3	2	5
Over 500	0	1	1	1	2

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[a] Wind speed of 3 to 5 mph; aircraft speed 90 to 100 mph; neutral stability.

[b] Cone-type nozzles for spraying.

[c] Drift to 1,000 ft or more from target area.

In the next section the type of equipment and method of pesticide application on agricultural crops--with specific consideration given to corn, sorghum, and apples--is examined, and the likelihood of drift is quantified. Tables 9, 13, and 16 on the preceding pages are used to assist in estimating the percentages of pesticide lost due to drift, and are referred to frequently.

Likelihood of Pesticide Drift in Agriculture

The information examined and developed to this point is now applied to the actual field conditions and operations experienced in agriculture. The objective of this section is to develop the estimates of drift losses that occur when pesticides are applied to crops, taking into consideration the method of application, the application equipment, and the pesticide formulations available.

A number of field tests have been conducted in the past by various researchers to determine the amount of drift involved under various circumstances. Some of these studies are presented in Appendix A, and are used as a source of information to assist in estimating the likelihood of drift in agricultural pesticide applications. The information developed previously and the field studies presented in Appendix A form the basis for the estimates given later, which show a detailed picture of drift in agricultural pesticide applications. In order to arrive at these estimates, the following sections are discussed:

1. Agricultural applications of pesticides and drift; and

2. Drift from agricultural pesticide application--quantities.

Agricultural Applications of Pesticides and Drift - The crops grown in the United States are diverse. Pesticides used to treat the crops are available to agriculture in a wide variety of chemical compounds, formulations, and mixtures. Application equipment available for dispensing the pesticides onto the crops ranges from large, expensive aircraft to inexpensive backpack units. No study of agricultural pesticide applications can cover the many methods used to treat the crops in the U.S.

The objective of this section is to discuss the most common methods of pesticide application in agriculture presented earlier while giving particular attention to the problem of drift associated with each technique. Attention is focused on field crops and orchards since the three study crops are corn, sorghum, and apples. An estimation is made of the amount of drift accompanying each application procedure. These estimates are then summarized to show the likelihood of pesticide drift in agriculture when applying pesticides in a certain manner.

The discussion of drift in agricultural pesticide applications is examined below and is divided into three sections for convenient presentation. These sections are:

1. Dust applications;

2. Granular applications; and

3. Spray applications.

The most common methods of applying the above formulations are presented in each section.

Dust applications - Dust, usually formulations of fungicides, are primarily used on orchards with small amounts used on vegetables, ornamentals, etc. The use of dusts on field crops is negligible. The discussion here is concerned only with the drift problems of treating trees with pesticidal dusts.

The likelihood of drift from dust applications is very high. The fine particle sizes have a low sedimentation rate and a low impaction efficiency which subjects them to the vagaries of shifting wind speeds and turbulence for an extended period of time. The problem is magnified by the fact that aircraft fly higher to dust than to spray liquids since a heavy dose of dust ends up in the middle of the swath with the methods commonly used.

Table 15 (p. 63) shows that particles with a size less than 50 μ have a greater than 90% chance of drifting when released at a height of 20 ft, and an 80% chance of drifting when released at a height of 10 ft. Even at a height of only 3 ft the chance of drift exceeds 40%. A height of 20 ft or more is common in aircraft dusting of orchards, while an average height of 10 ft is common for dusts blown onto trees from ground rigs.

Investigations of dust drift by various researchers seem to confirm that drift of dusts is very high. Fisher6/ reported that impaction efficiencies of less than 8% are found with particles below 50 μ in orchards. Splinter6/ reported that only 10 to 20% of the dust emitted in treating crops is normally found on the crop itself. Tests conducted by Witt in Arizona11/ showed that at all points downwind from the target area, the amount of dust deposited was four to 10 times higher than the amounts of spray deposited when simultaneous aircraft applications of toxaphene dust (4 lb/acre) and toxaphene emulsion (5 gal/acre) were conducted at wind speeds of 3 to 4 mph, inverse conditions, and a 60°F air temperature. Table A-2 (Appendix A) shows that dust drift amounted to 86% in a test conducted with aircraft.

In actual practice attempts have been made to reduce dust drift by wetting the dust as it discharges or by electrostatically charging the dust.[8] These efforts have produced some positive results and did reduce drift somewhat. Splinter[6] reported that electrostatic charging of dusts doubled the amount of dust deposited on the crop (20 to 40%). However, these techniques add expense to the dusting operation and are not widely used.

The discussion on impaction efficiencies in an earlier section of this report indicated that impaction efficiency increases with particle speed. Airblasters use high volumes of air (as much as 100,000 cfm in some cases) and high discharge velocities (over 100 mph in some cases). This technique, however, does not improve impaction efficiency of particles that miss the initial target or fail to impinge shortly after discharge. Wilson[8] tested an airblast sprayer that delivered 26,000 cfm at 90 mph, and found that air velocities at distances of 6, 18, 30, 42, and 54 ft were 21, 17, 14, 6, and 5 mph, respectively. Therefore, any particles that do not impact upon the target shortly after discharge slow down rapidly and are highly subject to drift as a result.

One other point needs consideration before estimating the likelihood of dust drift. Dusts tend to agglomerate due to their small size and electrostatic forces. No matter how finely they are dispersed, some agglomeration takes place, and when it does, the effective particle size of the agglomerated dust particle is increased. This phenomenon helps to reduce dust drift below theoretical estimates made based on particle size alone.

Two types of application methods and the associated drift are now considered. The first method is aerial application of dusts to orchard trees. Aircraft fly just over the trees at a height of 20 ft or more. The dust particles can contact the trees by sedimentation from the vertical direction or by impaction in a horizontal direction. Table 15 (p.63) shows that dust particles, which are 50 μ or less in size, have a 90% or greater potential to drift over 1,000 ft from the target before sedimentation occurs. Table 8 (p.51) shows that the impaction efficiency of particles, whose size is 40 μ or less, is 40% or less (drift potential, therefore, is 60% or greater). In addition, the turbulence caused by the wake of the aircraft, and the wing-tip vortices, tend to lift many of the particles up higher than the height at which they are released. These facts and the studies previously mentioned indicate that dust drift can be as high as 90% from aircraft. On the other hand, particle agglomeration and filtration of the airborne dust particles by many trees throughout the orchard (even with the low impaction efficiency) can reduce this amount somewhat. The studies previously mentioned indicated that between 70 and 90% losses were observed. Taking all of this into consideration, the estimated drift loss from aerial application of dusts in orchards is between 70 and 90%.

The other method considered is airblasting the dust onto the trees from a ground rig. Both hand-guns and nozzles mounted on the airblast unit are used. Two advantages this method has over aircraft application is that many particles do not get to the height at which aircraft fly and more control over the placement of the particles is obtained (aircraft blanket an orchard while ground rigs can treat individual trees). However, to maintain complete coverage ground airblasters have to aim at the tops of the trees and blow particles upward. Many of the particles become airborne in this manner. As was mentioned previously, particles which do not impact immediately lose their initial velocity and the impaction efficiency of these particles rapidly falls. Considering all of these facts, the amount of drift associated with orchard airblasters is less than that of aircraft, but not a great deal. The estimated drift loss from ground rig airblasters, then, is 60 to 80%.

Granular applications - The likelihood of drift from granular applications appears to present no drift problems since the granules most commonly used are sized to be 250 μ or greater. The screening operation, however, does not entirely eliminate the small particles (10% may be larger or smaller than the designated size when the NACA Granular Pesticide Committee guidelines are followed). Once the granules are packaged in bags they are subject to breakage and crushing during handling and transportation. Finally, the granules are subject to further size reduction when passing through the mechanical dispersal process of the pesticide applicator.

A study by Meyers and Lovely (1957)12/ conducted on an attapulgite RVM 30/60 granular determined that 5.5% of the material passed through a 60 mesh screen prior to being subjected to passage through an applicator. The weight of particles below 60 mesh (250 μ) after the granules were passed through a variety of metering devices found on applicators ranged from 6.0 to 9.1%. Thus, the weight of particles below the stated minimum size is presumably 5 to 9% of the total weight of granules applied.

No statistics were available on the particle size distribution of the particles below 250 μ that were measured in the above study. On a weight basis the percentage below 50 μ (dust) is quite insignificant, and is assumed to be about 10% of the subsized particles. The 50 to

100 μ range is assumed to be about 20% of the total weight, leaving the remaining 70% in the 100 to 250 μ range. Only the particles below 100 μ have a significant drift potential, as shown in Table 15 (p.63).

Using the above assumptions gives the result that about 1% (10% times 5 to 9%) of the total weight of the granules is in the sub-50 μ range, and about 1.5% (20% times 5 to 9%) of the total weight of the granules is in the 50 to 100 μ particle range. Since most of the herbicides and insecticides applied above the soil are either 25/50 or 30/60 mesh, then all aerial applications, boom-type applications, and centrifugal applications are subject to some drift.

Table 15 (p.63) shows the potential for drift at various release heights in 3 to 5 mph winds. Combining the values in Table 15 and the above information gives the following estimates for drift from granular applications (Table 18):

Table 18. ESTIMATED DRIFT POTENTIAL OF GRANULAR PESTICIDE APPLICATIONS

Application and method of application	Release height (ft)	Average drift potential for a particle whose size is: ≤ 50 μ	50 to 100 μ	Likelihood of drift beyond 1,000 ft
Aircraft, broadcast	10	90%	30%	1.5%
Boom, broadcast	3	70%	10%	1%
Boom, band	1/2	30%	0%	< 0.5%
Centrifugal, broadcast	3	70%	10%	1%
Planter, band	1/2	30%	0%	< 0.5%

Note: The drift potential for each size range is multiplied by the weight of particles in that range (1 and 1.5%, respectively) to determine the percent drift.

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Spray applications - Spray applications vary widely in formulations, methods of application, and application equipment used. For a discussion of drift it is most convenient to separate the spray operations into ground and aerial equipment applications. These two sectors can then be subdivided as required to cover the many facets of operation involved in each sector. The following discussion addresses ground equipment and aerial equipment separately.

Ground equipment - In addition to the information given earlier on formulations, methods of application, nozzles, volume of spray per acre, and application heights used in ground equipment pesticide application operations, it is also necessary to know the droplet size VMD's and the droplet size spectrums involved in spray applications to determine the drift potential of various spray operations. This subject and the likelihood of drift is discussed below for both field crop and orchard spraying by ground equipment.

Field crops - The likelihood of drift from ground spraying operations in field crops can be determined from Table 16 (p.63) and the droplet size VMD and droplet size spectrum for water emulsions and wettable powder formulations given in Tables 12 and 13 on the preceding pages. The typical operating parameters used in field crops and the associated droplet size VMD and droplet spectrum are given in Table 19 on the following page. Table 16 shows that particles greater than 100 μ released from a height of from 6 in. to 1.5 ft have a negligible chance of becoming drift. Those released at a 3 ft height have a very small chance of drifting in the 100 to 120 μ range. These statistics show that the chance of drift to 1,000 ft or more from the operations listed in Table 19 is negligible with the exception of booms applying sprays to the plants.

Foliar application operations using cone nozzles operate anywhere from 3 to 7 ft above the ground, and produce finer sprays than the soil application equipment. The table above shows that with ULV spraying the droplets produced below 100 μ can vary from 2 to 15% by volume, and LV spraying produces droplets below 100 μ at the rate of about 1% by volume. At a height of 3 to 7 ft, most of the water in these droplets will evaporate to dryness before reaching the ground if they do not impinge upon the plant. Therefore, the opportunity for drift exists under these circumstances and cannot be considered negligible.

The degree to which drift occurs depends upon the number of droplets that do not contact the plant and, are, therefore, airborne between the nozzle and the ground. This is difficult to determine, and no information was available on the subject under actual field conditions. Since small particles have a low impaction efficiency, it is assumed that most of the

Table 19. TYPICAL OPERATING PARAMETERS, DROPLET SIZE VMD'S, AND DROPLET SIZE SPECTRUMS ENCOUNTERED IN FIELD CROP SPRAY APPLICATIONS

Application method	Nozzle type	Pressure (psi)	Volume	Drop VMD	Drop spectrum Volume % less than specified size
Boom, broadcast	Fan spray	20-40	ULV	300-400	0 < 100 μ
Boom, broadcast	Fan spray	20-40	LV	350-600	0 < 100 μ
Boom, broadcast	Flooding	10-40	LV	a/	0 < 100 μ
Boom, band	Fan spray	20-40	ULV	300-400	0 < 100 μ
Boom, band	Fan spray	20-40	LV	350-600	0 < 100 μ
Boom, foliar	Cone spray	40-80	ULV	150-250	2 to 15 < 100 μ
Boom, foliar	Cone spray	40-80	LV	250-400	1 < 100 μ
Boomless, broadcast	Flat spray	10-40	LV	b/	0 < 100 μ

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a/ No information available on flooding nozzles but they are used to produce coarse droplet VMD's, 500 μ or greater, and have negligible volume of droplets less than 100 μ.

b/ No information available, but are similar to fan spray nozzles except that the output per nozzle is much higher (about 10 times higher) at the same operating pressures. This means that droplet size VMD is higher than for fan spray broadcast, and is not a drift problem.

particles below 100 μ do not contact the plant and become airborne. Table 16 (p.63) shows that these small particles have about a 70% chance of drifting over 1,000 ft. This is particularly true of wettable powder formulations, which have small particle sizes (most < 20 μ), since complete evaporation takes place before sedimentation of the droplet on the ground, and only the wettable powder particle remains after evaporation takes place.

Assuming an average value of about 10% by volume for droplets less than 100 μ in ULV operations, this means that about 7% (70% times 10%) of the spray volume drifts to a distance of over 1,000 ft. For LV operations only about 1% by volume is subjected to drift and the 1% figure is taken as the volume that drifts over 1,000 ft.

To further substantiate the findings above, Table 20[14] gives the calculated deposit rates of various drop size VMD's to a distance of 1,000 ft when sprays are applied by ground equipment from a 3-ft height above the ground.

Table 20 shows that a 100 μ drop VMD will have only 20% drift beyond 1,000 ft, and all of the operations discussed in this section have drop VMD's above 300 μ with the exception of the foliar application. If the percentage of droplets under 100 μ have a VMD of, say 50 μ, then the calculations above show that 62% of these particles drift. The assumption of 70% drift for the small particles does not seem unreasonable, considering the fact that a small fraction of the particles above 100 μ will drift also.

The likelihood of drift of the operations in this section are given in Table 21.

Table 20. CALCULATED DEPOSIT RATES (%) OF VARIOUS DROP SIZE RANGES APPLIED BY GROUND EQUIPMENT UNDER CONDITIONS OF NEUTRAL OR SMALL TEMPERATURE GRADIENT IN 3 TO 5 MPH WINDS

Drop size range (VMD, µm)	Percentage deposit (cumulative) downwind[a]				
	49 ft	98 ft	327 ft	457 ft	984 ft
10	0	1	3	3.3	3.5
25	1.0	1.5	5	10	13
50	10	25	30	35	38
100	25	50	70	75	80

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[a] Dispersal of pesticide made at 3 ft above the ground.

Source: Akesson, N. B., and Yates, W. E., "Physical Parameters Relating to Pesticide Application," personal communication.

Table 21. THE LIKELIHOOD OF DRIFT IN GROUND EQUIPMENT SPRAY APPLICATIONS

Operation	Likelihood of drift
Boom, broadcast	< 1%
Boom, band	< 1%
Boomless, broadcast	< 1%
Boom, foliar, ULV	7%
Boom, foliar, LV	1%

Orchards - The likelihood of drift varies substantially with the type of applicator used. Drift from herbicide applications to the soil is negligible since flooding nozzles and flat fan nozzles are commonly used in conjunction with dilute sprays and keep drift at a very minimum. If this practice is not followed, severe damage to the trees results from contact with the herbicides commonly used. Drift from high volume spraying of the trees with spray guns, and low volume and ultra low volume spraying with air blasters is not negligible.

High-volume, high-pressure spraying is normally done at pressures of about 600 psi.[9] The spray is directed up, over, and at the tree to insure complete spray runoff. No information was found on the droplet VMD's normally used in this operation, but they are assumed to be about 300 to 500 μ VMD at the pressure and spray volumes used. The spectrum of droplets, however, is much wider than at lower pressures.

Since information on this operation was not obtained, an estimate must be made. Table 12 (p.56) shows that a D10-25 hollow cone nozzle operating at 50 psi produces a drop VMD of 410, and 0.5% of the volume of droplets formed are less than 100 μ. A D10-45 hollow cone nozzle operating at 50 psi produces a drop VMD of 470 μ, and 1.0% of the volume of droplets formed are less than 120 μ. Since spray guns use nozzles similar to hollow cones and operate at very high pressures, the assumption is made that about 5% of the drops formed are less than 100 μ in size.

Table 16 (p.63) shows that at a release height of 10 ft, about 80% of the drops below 100 μ drift. The height of 10 ft is used as an average height since the spray is directed up to treat the tree. Table 16 also shows that 200 μ particles have a 15% drift potential. Taking into account the filtration of drifting particles by trees throughout the orchard, and assuming that the filtration effect reduces the drift by an amount equal to the drift experienced by particles above 100 μ, we have an estimated drift of 80% of the sub-100 μ particles (5% of the total volume), or a total estimated drift of 4% of the amount applied.

Orchard airblasters are commonly used for spray applications to trees today. They are also the largest source of drift in sprays applied from ground equipment. A search of the literature has shown that airblast sprayers are comparable to aircraft in quantities of drift emitted.[22,23]

The use of airblast sprayers has increased since they can spray concentrations of pesticides that are 6X or higher and achieve good coverage. At a 6X concentration, about 50 gal. of solution per acre is required, which is considered low volume.[14] Most conventional units are capable of applying spray mixtures up to 6X concentration, and some newer machines with special metering pumps can deliver mixtures as great as 33X concentration. The recommended application procedure is to apply two-thirds of the spray to the top one-third of the tree, and the remaining one-third to the lower two-thirds of the tree. Extensive research has shown this procedure is required to get uniform coverage of the entire tree.[9]

Airblasters use stationary nozzles mounted on the unit, normally in a semicircular arrangement directed up towards the foliage to dispense the spray. When applying concentrate solutions (such as 33X) the spray is applied at the rate of about 10 gal/acre or less, which is considered ultra low volume. The droplet VMD is in the aerosol range of about 50 to 100 μ for this operation (sometimes called mist blowing). When spraying the more conventional concentration of 6X, the droplet VMD is about 150 to 250 μ and is considered low volume (about 50 gal/acre). The fact that airblasters use high volumes of air (60,000 to over 100,000 cfm) and project the droplets at high speeds of 80 mph or greater makes the drift hazard great.

The drift hazard in orchards is high since the tree tops can be 20 to 30 ft from the sprayer when the tree spacings are 30 to 40 ft. Even with an airflow of 50,000 cfm, the time required for impingement of the small droplets on the tree from the time of discharge can be 1 to 5 sec. This allows time for the droplets to both slow down and undergo evaporation.[6] Since two-thirds of the spray is directed towards the treetop, most of the droplets will reach a height of 20 ft or greater.

As previously mentioned in the discussion on dusts, the velocity of the droplets slows down considerably as the distance of travel from the airblaster increases. By the time the droplets reach the tree they are traveling at a speed of about 20 mph or less when the distance is 30 to 40 ft. Table 8 (p.51) shows that the impaction efficiency of particles whose size is 40 μ or less is under 40% at 3 to 5 mph, and that 100 μ particles have impaction efficiencies of about 80%. If the particles do not impinge on the target tree, they undergo further speed reductions down to the wind speed of the atmospheric air, and have very low impaction efficiencies at this point.

To further add to the problem of drift is the fact that when low volume sprays (and volatile ultra low volume concentrates) are applied, evaporation reduces the particle size formed at emission to a smaller size yet. Figure 8 (p.51) shows that in a distance of 15 ft, all water droplets of 150 μ or less evaporate to dryness. This means that by the time the pesticide particle reaches the tree it is a dust (in the case of wettable powders) or the liquid pesticide concentrate itself, since all the dilution water has evaporated. This fact combined with the others mentioned above indicates that the drift potential for airblast spray applications is indeed high.

A study given in Appendix A conducted by Ware et al., compared the drift from a mist-blower to that of an airplane application. They found that the mist-blower spray, with a droplet VMD of 100 μ in the target area, produced greater amounts of drift at all distances up to 1/2 mile than did the airplane spray. The conclusions were that the high initial velocity (90 mph) and smaller droplet size (100 versus 140 μ) of the mist-blower contributed to this fact.

To estimate the drift potential of airblasters is difficult since the amount of initial impingement of sprayed drops on the target tree is unknown. Table 9 (p.53) shows that the droplet VMD size range of 50 to 100 μ (coarse aerosols), typical for ULV airblast applications, produces 60% of the drops by volume in sizes less than 100 μ. In the 100 to 250 μ VMD range, typical for LV airblast operations, only 16% of the drops by volume have sizes less than 100 μ. Assuming that flash evaporation occurs with LV particles and that by the time they reach the tree they are under 40 μ in size, the impaction efficiency of these drops is about 20%. Table 16 (p.63) shows that at heights of 3 ft or more, 40 μ particles have greater than a 95% chance of drifting over 1,000 ft.

Combining all of these statistics gives Table 22.

Table 22. LIKELIHOOD OF DRIFT FROM AIRBLASTERS

Operation	% Particles below 40 μ	Impaction efficiency (%)	Percent particles airborne	Likelihood of drift (%)
Airblast, ULV	60	20	48	45
Airblast, LV	16	20	13	12

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These figures take into account only the particles emitted from the airblaster that are 100 μ or less at the time of emission. The ULV operation emits all of the particles at a size below 180 μ (Table 9, p.53), and many of the 100 to 180 μ particles will drift also. If the impaction efficiency of 20% is used with all of the ULV droplets (100%), then the drift potential increases to 75% (95% times 80%). In the same manner about 50% of the LV droplets by volume are 150 μ or less (Table 9). If the impaction efficiency of 20% is used with all these droplets (which will evaporate in the 15 ft distance), then the drift potential increases to 45% (95% times 50%).

Considering all of the statistics presented above, and the filtration effect of all the trees in the orchard (at collection efficiencies below 10%), the estimates for the likelihood of drift beyond 1,000 ft in orchards when spraying with airblasters is: (a) ULV airblasting, 40 to 70%; and (b) LV airblasting, 10 to 40%.

Aerial equipment - In addition to the information given earlier on formulations, methods of application, nozzles, volume of spray per acre, and application heights used in aerial equipment pesticide application operations, it is also helpful to know the droplet size VMD's and droplet size spectrums commonly used in agriculture. The droplet size VMD and the droplet size spectrum for water emulsions and wettable powder formulations are given in Tables 12 and 13 on the preceding pages. The pressure of 50 psi in those tables is high (40 psi normal), but was the only information available. These tables show that ULV applications have droplet VMD's between 200 and 250 μ, and the percentage of drops below 120 μ is 10% by volume. The LV applications have droplet size VMD's of 250 to 500 μ, and the percentage of drops below 120 μ are 5% by volume. However, the determination of drift from aerial equipment applications must be made with a different approach than that used with ground equipment since aerial applications differ markedly from the other types of equipment previously discussed. The basic concepts and parameters discussed previously do not completely predict the drift from aircraft for two reasons: (a) the effect of the speed of the airplane; and (b) the turbulence created by the aircraft itself. To better understand how drift from aircraft occurs, a look at what is involved is helpful.

First, the drift from airplanes and helicopters is not a great deal different, since helicopters flying at 15 mph or greater have similar turbulent conditions to airplanes.[1] Only when they fly below this speed, or hover, does the effect of the downdraft become significant. Since most helicopters fly at speeds of 40 to 60 mph when applying pesticides, the two types of aircraft have similar circulation patterns. (Helicopters normally do not spray pesticides when hovering due to the high risk of contaminating the helicopter itself.) Figures 9 and 10[12] show the vortex and circulation patterns of both a fixed wing monoplane and a helicopter. Notice that the patterns are similar when the speed of the airplane is 80 mph and the helicopter speed is 15 mph. Therefore, helicopters and fixed-wing aircraft are considered to have similar drift potentials and are both hereafter designated as aircraft.

The effect turbulence created by the aircraft has on droplet dispersal is complex. The air currents that aircraft create cause an upward motion of the air at the wing tips and a downwash under the aircraft. (Fixed-wing aircraft also have a propeller wake with a rotational component.) As a result of these air currents small particles can be projected up 15 to 20 ft in the air after being released from a boom less than 10 ft off the ground. Tests with helicopters showed that the wing tip vortices are reduced at higher forward speeds. A comprehensive study by Reed showed that drops as large as 210 μ were given a looping trajectory by the wing tip vortices.[12]

The complexity of the above factors shows that no simple estimate can be made on drift without field test data. The nine field studies presented in Appendix A are given to support and document the estimates made here on drift from aerial spray operations. A brief examination of these studies is given here, and then the estimates are made based on the data presented.

ULV applications:

1. Study (1), Table A-1, shows that pesticide applications in the 100 to 300 μ VMD range are subject to drift to 1,000 ft in 3 to 5 mph winds when released by aircraft. The amount of drift varies from 20 to 60% of the volume applied.

2. Study (3), Table A-4, shows that ULV spray applications (1/2 pt to 1/2 gal/acre) by aircraft are deposited on-target in the range of 5 to 50%, depending on release height and air wind speeds. At low wind speeds of 2 mph, only 50% of the spray drifted out of the target area, whereas in 10 mph winds, the drift ranged from 70 to 90%. By comparison, diluted sprays (1 to 1-1/2 gal/acre) drifted more than ULV sprays.

3. Study (4), Table A-5, points out the fact that ULV aerial applications, applied at a height of 5 ft and at an aircraft speed of 80 mph, drifted 1,000 ft or more downwind from the target. The amounts of drift to this distance were 48 to 60% of the amount applied.

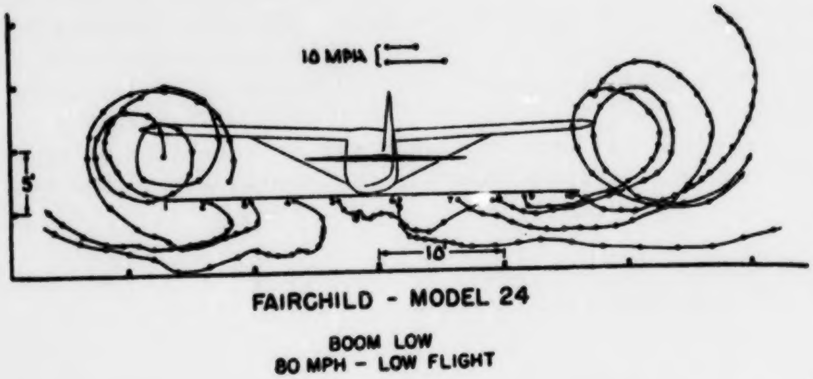
10 MPH
5'
10'
FAIRCHILD - MODEL 24
BOOM LOW
80 MPH - LOW FLIGHT

Figure 9. Vortex patterns in the wake of a passing high-wing monoplane.

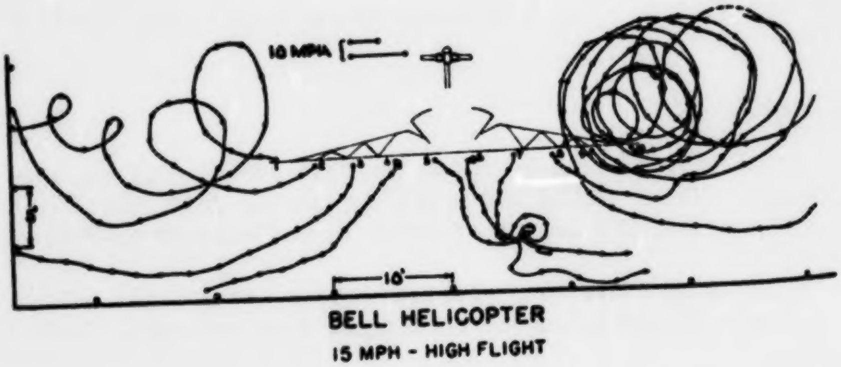
10 MPH
5'
10'
BELL HELICOPTER
15 MPH - HIGH FLIGHT

Figure 10. Vortex patterns in the wake of a helicopter.

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4. Study (5), Table A-6, shows that applications of undiluted pesticide (about 1 pt to 1/2 gal/acre) averaged 62% drift beyond a 3/8 mile distance downwind in four tests. At an application height of 8 ft, 82% of the azinphosmethyl (1 pt/acre) drifted beyond 1/2 mile, while at a 30-ft application height, only 38% drifted downwind. The malathion (1/2 gal/acre) drifted about the same at both 8 and 30 ft heights of application. The percent drift beyond 3/8 mile for each height was 69 and 61%, respectively.

These studies indicate that the range of drift for ULV applications is quite wide. A summary of these studies shows that:

Study	Drift beyond 1,000 ft (%)	Wind speed (mph)
(1)	20-60	3-5
(3)	50, 70-90	2, 10
(4)	48-60	Not given
(5)	38-82	Not given

Study (1) includes VMD's up to 300 μ which are too high for most ULV spraying, so the low percentage is too low. Study (3) shows drift to only 100 ft, not 1,000 ft, so these figures are high for drift to 1,000 ft. The average value for drift in Study (5) was 62%.

Taking all these facts into account places the estimated range of drift for ULV applications at moderate (3 to 5 mph) wind speeds between 40 and 60%.

LV applications:

1. Study (1), Table A-1, indicates that aerial applications of sprays with a droplet VMD of 300 to 400 μ are subject to drift beyond 1,000 ft in 3 to 5 mph winds. The amount of drift varies from 10 to 30%.

2. Study (1)a, Table A-2, also shows that for a large number of tests the average percent drift out of the target area was about 47% for LV applications.

3. Study (4), Table A-5, shows that 55% of a 2 gal/acre spray formula drifted over 1,000 ft from the target. Only one test was performed.

4. Study (5), Table A-6, indicated that drift from a diluted spray formulation ranged from 4 to 54% drift beyond a distance of 3/8 mile downwind. The average drift was 29% for the four tests conducted.

5. Study (7) showed that the drift from a LV aerial application was about five times greater than for a high clearance ground sprayer. (Note: This study previously determined that the drift range for the ground rig is about 7%, making drift from the aerial application about 35%.) These studies indicate that the range of drift for LV applications is quite wide. A summary of these studies shows that:

Study	Drift beyond 1,000 ft (%)	Wind speed (mph)
(1)	10-30	3-5
(1)a	47	Various speeds
(4)	55	Not given
(5)	4-54	Not given
(7)	35	1-2

Study (1)a gives drift from the target area only and is too high for drift to 1,000 ft. The average drift for Study (5) was 29%.

Taking all the above facts into account places the estimated range at 10 to 40% drift, primarily since Study (1) was developed over a long period of time and the other studies do not disagree to any extent.

The next section summarizes the findings of this section and puts them all into one table.

Drift From Agricultural Pesticide Applications - Quantities - This section has one purpose, and that is to bring all of the estimates on drift that were made in the previous section into one place, Table 23. This table lists all of the types of equipment considered in the previous section; the method of pesticide application used by each equipment type; the target; and the volume of spray application. With each type of operation shown in Table 23, the estimated percent drift to 1,000 ft from the target is given. The meteorological conditions assumed with these estimates are 3 to 5 mph wind speeds, neutral atmospheric stability, warm temperatures, and a relative humidity of 50% or less.

Table 23. LIKELIHOOD OF PESTICIDE DRIFT DURING CROP TREATMENT IN AGRICULTURE BY METHOD OF APPLICATION

Formulation	Equipment type	Pesticide application method[a]	Target	Spray application volume[b]	Estimated percent drift over 1,000 ft from target[c]
Dust	Aircraft, venturi	Air, foliar	Trees	-	70-90
	Airblaster	Ground, foliar	Trees	-	60-80
Spray	Tractor, boom sprayer	Ground, foliar	Plants	ULV	5-10
		Ground, foliar	Plants	LV	1
		Ground, broadcast	Soil	LV	Negligible
		Ground, broadcast	Soil	HV	Negligible
		Ground, band	Soil	ULV	Negligible
		Ground, band	Soil	LV	Negligible
	Tractor, boomless sprayer	Ground, broadcast	Soil	LV	Negligible
		Ground, broadcast	Soil	HV	Negligible
	Spray gun	Ground, foliar	Trees	HV	3-5
	Orchard airblaster	Ground, foliar	Trees	ULV	40-70
		Ground, foliar	Trees	LV	10-40
	Aircraft, boom sprayer	Air, foliar	Trees	ULV	40-60
		Air, foliar	Trees	LV	10-40
		Air, foliar	Plants	ULV	40-60
		Air, foliar	Plants	LV	10-40
		Air, broadcast	Soil	LV	10-40
Granular	Aircraft, venturi	Air, broadcast	Soil	-	1-2
	Spreader, centrifugal	Ground, broadcast	Soil	-	1
	Spreader, boom	Ground, broadcast	Soil	-	1
		Ground, band	Soil	-	Negligible
	Planter	Ground, band	Soil	-	Negligible

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[a] Air refers to pesticide application by aircraft, ground refers to pesticide application by ground rigs.

[b] HV = High Volume; LV = Low Volume; ULV = Ultra-Low Volume.

[c] Assumes a 3 to 5 mph wind; neutral atmospheric stability (S.R. = 0), air temperatures above 60°F; and a relative humidity of 50% or less.

The estimates for sprays given in Table 23 will change if the meteorological conditions change. The meteorological conditions given do not affect solid particles with the exception of wind speed. However, the estimates given in the table are generally good for winds below 10 mph, and pesticide applications made in winds greater than 10 mph are not recommended at all. To show how the relative magnitude of the estimates on spray drift change with different meteorological conditions, the following facts are given:

1. If wind speeds increase, drift increases.

2. If temperature increases, drift increases.

3. If relative humidity increases, drift decreases.

4. If the stability ratio increases (becomes positive), the drift decreases.

Table 23, then, represents the estimates for the amount of pesticide lost due to drift when treating crops in the manner indicated in the table. To estimate the actual losses of pesticides in agriculture due to drift during application requires the knowledge of: (a) the quantities of pesticides applied; (b) the manner in which they are applied; (c) the formulations used; and (d) the size of the crop being treated. With this information and Table 23, estimates can then be made as to the amount of pesticide that drifts away from the crop during application.

The next section makes estimates on the pesticide drift losses from the U.S. corn, sorghum, and apple crops for the year 1971 after the necessary information is given.

Estimated Pesticide Losses Due to Drift From the U.S. Corn, Sorghum, and Apple Crops (1971)

This section estimates the pesticide drift losses experienced in 1971 during treatment of the U.S. corn, sorghum, and apple crops. In order to do this, three basic parameters that directly affect pesticide loss due to drift are quantified for each crop and for each category of pesticide examined. The three parameters are:

1. Quantity of pesticide applied;

2. Pesticide formulations used; and

3. Method of application.

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Once these parameters are quantified, the amount of pesticide drift that occurs during crop treatment is estimated by using the values given in Table 23 for the likelihood of drift which accompanies each method of application.

Notice that the fourth parameter (size of the crop being treated) mentioned in the previous section is not included. This parameter is important since Table 23 only estimates the percentage of drift to 1,000 ft. However, the inclusion of this parameter involves a great deal of calculating and estimating since each individual farm (or groups of farms the same size) within the three study crops would have to be considered separately. (In other words, percentage drift from a small farm is greater than from a large farm since 1,000 ft from the target on a large farm is more often within the borders of the farm.) This parameter, therefore, is not considered in these estimates.

In practice, for one reason: the size of the farm does not make a great deal of difference. The amount of pesticide which drifts to 1,000 ft is dispersed in small particles, most of which are capable of drifting for miles. Only small amounts of the drift cloud will settle to the soil with incremental distances. This means that the difference between the amount of drift from a 100-acre farm and a 1,000-acre farm is about 10% of the total drift at 1,000 ft, and is not considered significant in the estimations in this section. (See Table 20, p.73, for the effect of distance on decreasing percentages of drift settlement to the ground.)

Another parameter held constant in the estimations in this section is the meteorological conditions. The percentages of drift in Table 23 are based upon the meteorological conditions given at the bottom of the table. Since these conditions are typical of actual field conditions, the assumption is made that the average or typical climatic conditions under which pesticide applications were made in 1971 are those given in Table 23.

Each crop is discussed in a separate section below. The pesticides lost due to drift from each crop are divided into four separate categories which are: (a) herbicides; (b) insecticides; (c) fungicides; and (d) other pesticides.

Estimated Pesticide Drift Losses from the U.S. Corn Crop (1971) - The pesticide losses due to drift during application from the 1971 corn crop are estimated in three separate parts: (a) herbicides and insecticides; (b) fungicides; and (c) other pesticides.

Herbicides and insecticides - The quantities of herbicides and insecticides applied to the corn crop (1971) are given in Appendix C, Table C-1. Herbicides accounted for 101,060,000 lb of pesticides used on corn, and insecticides accounted for 25,531,000 lb of pesticides used on corn.

The formulations for herbicides were primarily wettable powders and emulsions, with a small usage of granules and no dusts. Since no information is available on the exact amounts of spray formulations and granules used that year, the following assumptions are made, based on the method of application:

Ground application equipment - 10% granules, 90% spray.

Aerial application equipment - 30% granules, 70% spray.

The formulations for insecticides were primarily granules, with a small usage of spray and no dusts. Since no information was available on the exact amounts of spray formulations and granules used that year, the following assumptions are made, based on method of application:

Ground application equipment - 90% granular, 10% spray.

Aerial application equipment - 50% granular, 50% spray.

The method of application of insecticides and herbicides was documented in 1971. Corn farmers in the United States apply most of the pesticides to the crops rather than contracting the work to commercial applicators. The five state survey conducted in the Lake States Region[24] provides detailed information on this subject. Table 24 shows the amount of corn acreage treated by the farmers themselves and by custom applicators in the states of Michigan, Wisconsin, Minnesota, and Illinois, and these statistics are summarized below:

Pesticide	Time of application	Acres treated 1971 (000)	Acres (000) treated by: Self	%	Custom	%
Herbicides	Preemergence	14,553	11,985	82.4	2,568	17.6
	Postemergence	9,219	7,058	76.6	2,161	23.4
Subtotal		23,772	19,043	80.1	4,729	19.9
Insecticides	Preemergence	8,257	7,941	96.2	316	3.8
	Postemergence	437	320	73.2	117	26.8
Subtotal		8,694	8,261	95.0	433	5.0
Total		32,466	27,304	84.1	5,162	15.9

Table 24. PESTICIDE APPLICATION TO CORN, BY APPLICATOR, 1971[a]

		Percent of acres treated by:		Acres (000)	Acres treated by (000):	
State	Pesticide	Self	Custom operator	treated 1971	Self	Custom
Michigan	Herbicides:					
	Preemergence	86	14	1,252	1,077	175
	Postemergence	89	11	975	868	107
	Insecticides:					
	Preemergence	98	2	271	266	5
	Postemergence	22	78	3	1	2
Wisconsin	Herbicides:					
	Preemergence	72	28	1,815	1,307	508
	Postemergence	67	33	1,065	714	351
	Insecticides:					
	Preemergence	93	7	835	777	58
	Postemergence	59	41	75	44	31
Minnesota	Herbicides:					
	Preemergence	90	10	3,308	2,977	331
	Postemergence	72	28	3,764	2,710	1,054
	Insecticides:					
	Preemergence	98	2	1,663	1,630	33
	Postemergence	45	55	136	61	75
Illinois	Herbicides:					
	Preemergence	81	19	8,178	6,624	1,554
	Postemergence	81	19	3,415	2,766	649
	Insecticides:					
	Preemergence	96	4	5,488	5,268	220
	Postemergence	96	4	223	214	9
Total				32,466	27,304	5,162

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[a] Statistics from the following sources:
General Farm Use of Pesticides, 1971, Wisconsin Department of Agriculture.
General Farm Use of Pesticides, 1969-1971, Michigan Department of Agriculture.
General Farm Use of Pesticides, 1972, Minnesota Department of Agriculture.
Illinois Pesticide Use by Illinois Farmers, 1972, Illinois Department of Agriculture.

These four states harvested 22,161,000 acres of corn in 1971, or 30.4% of the total U.S. corn crop. From the above summary it is evident that about 80% of all herbicides were self-applied, and 95% of all insecticides were self-applied.

These figures are taken to be typical of the entire U.S. corn crop. Two other sources of information also confirm this assumption. Indiana reported[25] that in 1970 all herbicides applied to field crops (corn, soybeans, oats, wheat, barley, rye and hay) were self-applied on 86% of the acres treated and insecticides were self-applied on 95% of the acres treated. South Dakota reported in 1973 that 90% of the herbicides applied to corn and sorghum were self-applied, while 85% of insecticides were selfapplied. These two states harvested 9,350,000 acres of corn in 1971, or 12.8% of the total U.S. corn crop. All six states given here harvested 43% of the entire corn crop in 1971.

Since the above statistics represent the self-application versus custom application techniques used on almost half of the entire U.S. corn crop, they are treated as typical for the entire crop. Statistics summarizing the pesticide usage by applicator for the U.S. corn crop in 1971 are:

Pesticide	Time of application	Acres treated 1971 (000)	Acres (000) treated by: Self	%	Custom	%
Herbicides	Preemergence	46,900	38,500	82	8,400	18
	Postemergence	29,800	22,900	77	6,900	23
Subtotal		76,700	61,400	80	15,300	20
Insecticides	Preemergence	26,600	25,500	96	1,100	4
	Postemergence	1,400	1,000	73	400	27
Subtotal		28,000	26,500	95	1,500	5
Total		104,700	87,900	84	16,800	16

The method of application of the pesticides to the crops is also given in detail in the five-state survey. Farmers reported whether the pesticide applied, either self or custom, was a broadcast or band application. The broadcast application was further characterized as surface applied or incorporated into the soil. The results of the 1971 survey are given in Table 25.

The percentages in the table are based on the percentages of reports collected during the survey, not the acreage involved. This makes the statistics somewhat unreliable, but some general conclusions may be drawn. These interpretations are summarized below as being typical overall values for the entire U.S. corn crop:

		% Acres treated		
		Broadcast		
Pesticide	Time of application	Surface applied	Incorporated in soil	Band
Herbicide	Preemergence	50-80	5-15	10-30
	Postemergence	60-90	2-10	5-30
Insecticide	Preemergence	5-10	10-20	70-90
	Postemergence	50-80	5-15	20-40

Though these statistics are crude, they do show that most herbicides are broadcast, while most of them are surface applied rather than incorporated into the soil. Most preemergent insecticides are band applied while postemergent insecticides are broadcast. The percentages can vary widely with formulation, type of pesticide used, and geographical location so that no exact figures can be readily obtained.

The quantity of herbicide drift is estimated from the above assumptions, the statistics provided by the five state survey, and the values for percent drift given in Table 23 (p.82). In order to do this, the quantities of herbicides applied to the crop must be determined by formulation, by method of application, and by type of application equipment. The assumption is made, therefore, that the herbicides were distributed equally on the acres treated, since the statistics developed under the methods of application apply to acres treated, not pounds applied.

Table 25. PESTICIDE APPLICATION TO CORN, BY METHOD, 1971[a]

State	Pesticide	Method of application, broadcast[b]		
		Surface applied	Incorp. in soil	Band
Michigan	Herbicides:			
	Preemergence	82	5	13
	Postemergence	92	1	7
	Insecticides:			
	Preemergence	10	16	74
	Postemergence	100	0	0
Wisconsin	Herbicides:			
	Preemergence	89	6	5
	Postemergence	94	1	5
	Insecticides:			
	Preemergence	21	11	68
	Postemergence	61	10	29
Minnesota	Herbicides:			
	Preemergence	32	4	64
	Postemergence	84	0	16
	Insecticides:			
	Preemergence	7	6	87
	Postemergence	73	7	20
Illinois	Herbicides:			
	Preemergence Postemergence	49.5	16.0	34.5
	Insecticides:			
	Preemergence	6	24	70
	Postemergence	14	16	70

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[a] Statistics from the following sources:

General Farm Use of Pesticides, 1971, Wisconsin Department of Agriculture.

General Farm Use of Pesticides, 1969-1971, Michigan Department of Agriculture.

General Farm Use of Pesticides, 1972, Minnesota Department of Agriculture.

Illinois Pesticide Use by Illinois Farmers, 1972, Illinois Department of Agriculture.

[b] Percent of reports.

The amount of herbicides applied to the 1971 corn crop was 101,060,000 lb. Preemergent applications were 61% of the total, or 61,600,000 lb, and postemergent applications were 39% of the total, or 39,400,000 lb. Preemergent applications are divided into three methods: (a) soil surface broadcast, 70%; (b) soil incorporated broadcast, 10%; and (c) band, 20%.

Postemergent applications were also divided into three methods of application: (a) soil surface broadcast, 75%; (b) soil incorporated broadcast, 5%; and (c) band, 20%.

The applicators for the preemergent herbicides were: (a) self, 82%; and (b) custom, 18%; and for the postemergent herbicides were: (a) self, 77%; and (b) custom, 23%.

These statistics give the following information:

Time of application	Broadcast applications (000 lb)	Surface incorporated (000 lb)	Band applications (000 lb)
Preemergent	43,100	6,200	12,300
Postemergent	29,500	2,000	7,900

All applications made by the farmer himslf are assumed to be ground equipment applications. This leaves 18% of the preemergent herbicides available for aerial application by custom applicators and about half (or 10% of the total preemergent applications) of custom applications are assumed to have been made aerially. Likewise, only 23% of the postemergent herbicides were applied by custom applicators, and about half (or 10% of the total postemergent applications) of these applications are assumed to have been made aerially. All aerial applications are surface broadcast applications since banding or soil incorporating herbicides with aircraft is impossible.

Table 26 is constructed with the previous assumptions made on formulations used and the values given in Table 23 (p.82) for percent drift accompanying a particular type of application. This table shows that from about 800,000 to 3,000,000 lb of herbicides were lost during application due to drift from the 1971 U.S. corn crop. This represents a loss of 0.8 to 3.0% of the total herbicides applied that year.

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Table 26. ESTIMATED HERBICIDE DRIFT LOSSES FROM THE U.S. CORN CROP (1971)

Time of application	Method of application	Type of equipment	Formulation	Estimated percent drift over 1,000 ft from target (%)	Pounds applied (000)	Pounds lost (000) Low	Pounds lost (000) High
Preemergent	Broadcast, surface	Ground	Spray	Negligible	33,000	-	-
			Granular	1	3,700	39	39
		Air	Spray	10 to 40	4,300	430	1,720
			Granular	1 to 2	1,800	18	36
	Broadcast, incorporated	Ground	Spray	Negligible	5,600	-	-
			Granular	Negligible	600	-	-
	Band	Ground	Spray	Negligible	11,100	-	-
			Granular	Negligible	1,200	-	-
Subtotal					61,600	487	1,795
Postemergent	Broadcast, surface	Ground	Spray	Negligible	23,000	-	-
			Granular	1	2,500	25	25
		Air	Spray	10 to 40	2,800	280	1,120
			Granular	1 to 2	1,200	12	24
	Broadcast, incorporated	Ground	Spray	Negligible	1,800	-	-
			Granular	Negligible	200	-	-
	Band	Ground	Spray	Negligible	7,100	-	-
			Granular	Negligible	800	-	-
Subtotal					39,400	317	1,169
TOTAL					101,000	804	2,964

The quantity of insecticide drift is estimated from the above assumptions, the statistics provided by the five state survey, and the values for percent drift given in Table 23. In order to do this, the quantities of insecticides applied to the crop must be determined by formulation, by method of application, and by type of application equipment. The assumption is made, therefore, that the insecticides were distributed equally on the acres treated, since the statistics developed under the methods of application apply to acres treated, not pounds applied.

The amount of insecticides applied to the 1971 corn crop was 25,531,000 lb. Preemergent applications were 95% of the total, or 24,200,000 lb, and postemergent applications were 5% of the total, or 1,300,000 lb. Preemergent applications were divided into three methods of application: (a) soil surface broadcast, 5%; (b) soil incorporated broadcast, 15%; and (c) band, 80%.

Postemergent applications were also divided into three methods of application: (a) soil surface broadcast, 65%; (b) soil incorporated broadcast, 10%; and (c) band, 25%.

The applicators for the preemergent insecticides were: (a) self, 95%; and (b) custom, 5%; and for the postemergent insecticides were: (a) self, 73%; and (b) custom, 27%.

These statistics give the following information:

Time of application	Broadcast applications (000 lb)	Surface incorporated (000 lb)	Band applications (000 lb)
Preemergent	1,200	3,600	19,400
Postemergent	900	100	300

All applications made by the farmer himself are assumed to be ground equipment applications. This leaves 5% of the preemergent insecticides available for aerial application by custom applicators and about half (or 3% of the total preemergent applications) of custom applications are assumed to have been made aerially. Likewise, only 27% of the postemergent insecticides were applied by custom applicators, and about half (or 15% of the total postemergent applications) of these applications are assumed to have been made aerially. All aerial applications are surface broadcast applications since banding and soil incorporating insecticides with aircraft is impossible.

Table 27 is constructed with the previous assumptions made on formulations used and the values given in Table 23 (p.82) for percent drift accompanying a particular type of application. This table shows that from 50,000 to 180,000 lb of insecticides were lost during application due to drift from the 1971 U.S. corn crop. This represents a loss of 0.2 to 0.7% of the total insecticides applied that year.

Fungicides - Fungicides used in 1971 on corn were not specified by the U.S. Department of Agriculture report.[26] This report showed that a total of 1,732,000 lb of fungicides (excluding sulfur) were used on the category of crops which includes corn, wheat, sorghum, rice, tobacco, soybeans, alfalfa, and sugarbeets, as well as other grains and field crops. Obviously, the use of fungicides on corn (compared to herbicide and insecticide usages) was very small, and any losses of fungicides at the time of application due to drift from corn crops are negligible.

Other pesticides - Corn was treated with 443,000 lb of miscellaneous pesticides (Appendix C, Table C-1). Fumigants accounted for 386,000 lb and miticides accounted for the remaining 57,000 lb. Again, these quantities are small compared to insecticides and herbicides used on corn, and drift losses of these pesticides are negligible.

Estimated Pesticide Drift Losses From the U.S. Sorghum Crop (1971) - The pesticide losses during application due to drift from the 1971 sorghum crop are estimated in four separate parts: (a) herbicides; (b) insecticides; (c) fungicides; and (d) other pesticides.

Herbicides - The quantity of herbicides applied to the sorghum crop (1971) are given in Appendix C, Table C-5. Herbicides accounted for 11,538,000 lb of pesticides used on sorghum.

The formulations of herbicides were primarily wettable powders and emulsions, with a small usage of granules and no dust usage. Since no information is available on the exact amount of spray formulations and granules used that year, sprays are assumed to have accounted for 90% of all formulations, and granules are assumed to have accounted for the remaining 10% of the formulations.

Table 27. ESTIMATED INSECTICIDE DRIFT LOSSES FROM THE U.S. CORN CROP (1971)

Time of application	Method of application	Type of equipment	Formulation	Estimated percent drift over 1,000 ft from target (%)	Pounds applied (000)	Pounds lost (000)	
						Low	High
Preemergent	Broadcast, surface	Ground	Spray	Negligible	100	-	-
			Granular	1	500	5	5
		Air	Spray	10 to 40	300	30	120
			Granular	1 to 2	300	3	6
	Broadcast, incorporated	Ground	Spray	Negligible	400	-	-
			Granular	Negligible	3,200	-	-
	Band	Ground	Spray	Negligible	1,900	-	-
			Granular	Negligible	17,500	-	-
Subtotal					24,200	38	131
Postemergent	Broadcast, surface	Ground	Spray	Negligible	100	-	-
			Granular	1	600	6	6
		Air	Spray	10 to 40	100	10	40
			Granular	1 to 2	100	1	2
	Broadcast, incorporated	Ground	Spray	Negligible	-	-	-
			Granular	Negligible	100	-	-
	Band	Ground	Spray	Negligible	30	-	-
			Granular	Negligible	270	-	-
Subtotal					1,300	17	48
TOTAL					25,500	55	179

The method of application of herbicides is not known for 1971. The assumption is made that 10% of the herbicides were applied by aircraft, and 90% by ground equipment. All aerial applications are broadcast, and ground applications are assumed to have been divided into three methods of application as follows: (a) soil surface broadcast, 70%; (b) soil incorporated broadcast, 10%; and (c) band, 20%.

These assumptions and the values for percent drift given in Table 23 (p.82) are used to construct Table 28. This table shows that from 120,000 to 450,000 lb of herbicides were lost during application due to drift from the 1971 U.S. sorghum crop. This represents a loss of 1.0 to 3.9% of the total herbicides applied that year.

Insecticides - The quantities of insecticides applied to the sorghum crop (1971) are given in Appendix C, Table C-5. This table shows that a total of 5,729,000 lb of insecticides were used on sorghum in 1971.

The formulations and methods of application of insecticides used in 1971 were obtained from interviews with entomologists in the states of Texas, Oklahoma, Kansas, and Iowa, the leading sorghum producing states. The information obtained from these interviews indicates that 90% of all insecticides used on sorghum are aerially applied and only 10% of all insecticides are applied from ground equipment. Of the 90% aerial applications, two-thirds are liquid formulations applied to both the soil and plants, while one-third are granular formulations applied to the soil. Of the 10% ground equipment applications, 80% (8% of the total insecticides applied) are liquids applied to the plants, and 20% (2% of the total insecticides applied) are granules applied to the soil.

The above information and Table 23 (p.82) are used to construct Table 29, which shows the estimates for insecticide drift losses from the 1971 sorghum crop. This table shows that from 360,000 to 1,400,000 lb of insecticides were lost during application due to drift from the 1971 U.S. sorghum crop. This represents a loss of 6 to 25% of the total insecticides applied that year.

Fungicides - Fungicides used in 1971 on sorghum were not specified by the U.S. Department of Agriculture report,26/ which listed sorghum with corn, as previously mentioned in the fungicide discussion on the corn crop. The use of fungicides on sorghum is assumed to be small, as in the case of corn, and any losses of fungicides at the time of application due to drift from sorghum crops are negligible.

Table 28. ESTIMATED HERBICIDE DRIFT LOSSES FROM THE U.S. SORGHUM CROP (1971)

Method application	Type of equipment	Formulation	Estimated percent drift over 1,000 ft from target (%)	Pounds applied (000)	Pounds lost (000) Low	Pounds lost (000) High
Broadcast, surface	Ground	Spray	Negligible	6,100	-	-
		Granular	1	700	7	7
	Air	Spray	10 to 40	1,100	110	440
		Granular	1 to 2	100	1	2
Broadcast, Incorporated	Ground	Spray	Negligible	1,100	-	-
		Granular	Negligible	100	-	-
Band	Ground	Spray	Negligible	2,100	-	-
		Granular	Negligible	200	-	-
TOTAL				11,500	118	449

Table 29. ESTIMATED INSECTICIDE DRIFT LOSSES FROM THE U.S. SORGHUM CROP (1971)

Target	Type of equipment	Formulation	Estimated percent drift over 1,000 ft from target (%)	Pounds applied (000)	Pounds lost (000)	
					Low	High
Foliar	Ground	Spray	1	500	5	5
Foliar and/or soil	Air	Spray	10 to 40	3,400	340	1,360
Soil	Ground	Granular	1	100	1	1
	Air	Granular	1 to 2	1,700	17	34
TOTAL				5,700	363	1,400

Other pesticides - Sorghum was included in a broad category of crops--the same one mentioned previously under fungicides used on corn--that were treated with 3,334,000 lb of miscellaneous pesticides. Fumigants accounted for 3,124,000 lb, or over 90% of the total applied. Again, the use of miscellaneous pesticides on sorghum is considered negligible, and the losses of these pesticides are negligible also.

Estimated Pesticide Drift Losses From the U.S. Apple Crop (1971) - The pesticide losses during application due to drift from the 1971 apple crop are estimated in four separate parts: (a) herbicides; (b) insecticides; (c) fungicides; and (d) other pesticides.

Herbicides - The quantity of herbicides applied to apple orchards in 1971 is given in Appendix C, Table C-7. Herbicides accounted for only 197,000 lb of pesticides used in apple orchards. Their use presents a special problem in orchards since herbicides commonly used will severely damage the trees if contact between the trees and herbicides is allowed. Therefore, special precautions are taken to prevent herbicide drift to the susceptible trees.

Any drift of herbicides is negligible due to the small quantities used and the special measures taken to prevent damaging drift in orchards.

Insecticides - The *quantity* of insecticides applied to apple orchards (1971) is given in Appendix C, Table C-7. Insecticides accounted for 4,831,000 lb of pesticides used in apple orchards.

The *formulations* of insecticides were primarily wettable powders and emulsions, with a lesser amount of dust usage and no granular formulation usage. Since no information is available on the exact amounts of spray formulations and dust formulations used that year, sprays are assumed to have accounted for 80% of all formulations, and dusts are assumed to have accounted for the remaining 20% of the formulations.

The *method of application* of insecticides to apples in 1971 was primarily that of aerial spraying, airblast spraying, and high volume spraying. Since the relative amounts of each method are not known, the assumption is made that half the dusts were applied aerially to the trees, and that the other half of the dusts were applied to the trees with an orchard airblaster. The liquid sprays are assumed to have been applied both as an LV application with an airblaster--75% of the total spray applications--and as an HV application with a high pressure spray gun--25% of the spray applications. (Some aerial liquid spray application was undoubtedly performed, but the drift loss from aerial spray applications and LV airblaster applications are the same.)

The quantity of insecticide drift is determined from the above assumptions and the information given in Table 23 (p.   ). These data are used to construct Table 30, which shows the estimated insecticide drift losses from the 1971 apple crop. (All insecticide applications are foliar in apple orchards.) This table shows that from about 1,000,000 to 2,000,000 lb of insecticides were loss during application due to drift from the 1971 apple crop. This represents a loss of 21 to 42% of the total insecticides applied that year.

Fungicides - The quantity of fungicides applied to apple trees (1971) is given in Appendix C, Table C-7. Fungicides accounted for 7,207,000 lb of pesticides used in apple orchards.

The method of application and formulations used are assumed to have been the same as those for insecticides. Therefore, the percentage loss of fungicides was about the same as that for insecticides (between 21 and 42%) and the quantities of fungicides lost due to drift were between 1,500,000 and 3,000,000 lb in 1971.

Other pesticides - Miscellaneous pesticides applied to apple orchards (1971) consisted of 367,000 lb of miticides; 174,000 lb of plant growth regulators; and 7,000 lb of rodenticides. These pesticides brought the total miscellaneous pesticide use on apple orchards to 548,000 lb. This quantity is small relative to the usage of insecticides and fungicides on apples in 1971, and the drift loss of the miscellaneous pesticides listed above is negligible.

Table 30. ESTIMATED INSECTICIDE DRIFT LOSSES FROM THE U.S. APPLE CROP (1971)

Type of equipment	Formulation	Estimated percent drift over 1,000 ft from target (%)	Pounds applied (000)	Pounds lost (000)	
				Low	High
Airblaster	Dust	60 to 80	500	300	400
	Spray	10 to 40	2,800	280	1,120
Spray gun	Spray	3 to 5	1,000	30	50
Aircraft	Dust	70 to 90	500	350	450
TOTAL			4,800	960	2,020

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SECTION IV

PESTICIDE LOSSES AFTER APPLICATION AND BY MISCELLANEOUS DISCHARGES

INTRODUCTION

There are several potential sources of pesticide waste which occur both after pesticide application to the crop and due to miscellaneous pesticide discharges. These losses reduce the efficiency of pesticide usage in agriculture. The pesticide losses which occur after application are due primarily to the unwanted migration of effectively applied pesticides from the treated crop by the natural forces of runoff and soil erosion. Miscellaneous pesticide discharges into the environment result from pesticide spills and from disposal of unused pesticides and incompletely emptied containers.

This section examines both the transport of pesticides from crops by the mechanism of runoff and soil erosion and the miscellaneous discharges of pesticide spills and pesticide disposal. Each subject is given both a qualitative and a quantitative treatment as it is discussed. In the case of runoff and soil erosion, the amount of pesticides lost from the U.S. corn, sorghum, and apple crops (1971) is determined. Pesticide losses from spills and disposal are not determined quantitatively, since the nature of these subjects does not permit an accurate determination to be made.

Each of the above subjects are examined separately in the following discussion.

PESTICIDE LOSS DUE TO RUNOFF AND SOIL EROSION

The principal mechanisms of pesticide transport away from field crops after application are: (a) surface runoff including both sediment and water; (b) volatilization; (c) leaching to ground water; and (d) degradation by chemical, photochemical, or microbial processes. The magnitude of the losses vary with each pesticide and environmental condition. Generally, surface runoff, volatilization, and degradation are the dominant mechanisms for pesticide loss from cropland. Volatilization and degradation, however, are processes which are beyond the control of the farmer once the pesticide has been properly applied. Since this study deals with the inefficient use of pesticides, only surface runoff and erosion are considered.

Before discussing the mechanisms of runoff and erosion and their effect on pesticide losses from the study crops, it is important to realize that some of the losses occurring by these two mechanisms are, in reality, beyond man's control. Surface runoff and soil erosion occur even under the best soil conservation practiced today. The approach to this subject, then, must be one that examines not only the incidence of pesticide losses, but methods by which these losses can be reduced through man's efforts.

This section is divided into the following subsections:

1. Field Crop Runoff and Soil Erosion.

2. Management Practices in Field Crops.

3. Pesticide Losses in Runoff and Soil Erosion.

4. Estimated Runoff from the U.S. Corn and Sorghum Crops - Quantities.

5. Estimated Pesticide Losses from the U.S. Corn, Sorghum, and Apple Crops in 1971 - Quantities.

Field Crop Runoff and Soil Erosion

Pesticides applied to the soil of corn and sorghum crops are subject to removal from the crop by transport in runoff water and eroded soil. Runoff occurs in two different manners--overland and subsurface runoff. Overland runoff represents surplus water which leaves the crop above the soil surface, whereas subsurface runoff represents residual water not accommodated by the soil. Likewise, soil erosion occurs when wind transports soil at rest. Since most investigations of pesticide losses from crops due to runoff and soil erosion have studied surface runoff and the accompanying sediment losses, and since wind erosion and subsurface runoff are subject to less control than the other two mechanisms, only surface runoff and surface soil erosion by water are considered here.

Runoff and soil erosion occur from both natural and man-made events. Nature provides rain and man irrigates. Irrigation can cause erosion if water is applied at rates which exceed the rate of infiltration into the soil, and, consequently, water runs off the crop. By employing proper techniques to insure that irrigation to the point of runoff and soil transport away from the crop is avoided, the farmer also avoids pesticide loss during crop irrigation. Since irrigation is controllable, and the best interests of the farmer are served if excessive water (which is expensive and sometimes scarce) is not used, then pesticide losses from crops due to irrigation practices are most likely negligible. Therefore, this study examines rainfall events only.

The damage caused by raindrops hitting the soil at a high velocity is the first step in the runoff and erosion process. Raindrops shatter the soil granules and clods, reducing them to smaller particles and thereby reducing the infiltration capacity of the soil. The small soil particles are then detached by additional rainfall, and the force of the raindrops starts the movement of splashed soil downslope. When the rate of rainfall exceeds the rate of infiltration, depressions in the soil surface fill and overflow, causing runoff. The runoff water picks up the detached soil particles, and breaks the now suspended particles into smaller sizes. The flow of the runoff water transports the suspended soil particles, and together both the water and sediment move off the crop. This basic mechanism of soil erosion was defined by Meyer and Wischmeier1/ as falling into four categories: (a) soil detachment by raindrops; (b) transport by rainfall; (c) detachment by runoff; and (d) transport by runoff.

When rainfall occurs, the risk that pesticides in the soil will be transported from the field in the runoff water and/or sediment is great and is directly related to those factors which effect surface erosion. Factors which have been considered the most significant in affecting erosion of topsoil are:

1. Soil properties;

2. Slope characteristics;

3. Land cover conditions;

4. Rainfall characteristics; and

5. Conservation treatment.

Soil Properties - Soil properties affect both the detachment and transport processes. Detachment is related to soil stability (basically the size, shape, composition), and strength of soil aggregates and clods. Transport is influenced by permeability of soil to water which determines infiltration capabilities and drainage characteristics; by porosity, which affects storage and movement of water; and by soil surface roughness, which creates a potential for temporary detention of water.

Slope Characteristics - Slope characteristics are represented by the slope factor which defines the transport portion of the erosion process. It is exemplified by slope gradient and slope length, both of which influence the flow and velocity of runoff.

Land Cover Conditions - Land cover conditions affect detachment and transportation of soil. Land cover by plants and their residues provides protection from the impact of raindrops. Vegetation protects the ground from excessive evaporation, keeps the soil moist, and thus, makes the soil aggregates less susceptible to detachment. In addition, residues and stems of plants furnish resistance to overland flow, slowing down runoff velocity and reducing erosion.

Rainfall Characteristics - Rainfall characteristics define the ability of the rain to splash and erode soil. Rainfall energy is determined by drop size, velocity, and intensity characteristics of rainfall.

Conservation Treatment - Conservation treatment concerns modification of the soil factor or the slope factor, or both, as they affect the erosion sequence. Practices for erosion control are designed to do one or more of the following: (a) dissipate raindrop impact forces; (b) reduce quantity of runoff; (c) reduce runoff velocity; and (d) manipulate soils to enhance the resistance to erosion.[2]

The factors discussed above indicate that the amount of soil loss and runoff are within the control of the farmer to the extent that he uses good conservation practices. By minimizing runoff and erosion, the risk of pesticide loss is substantially reduced. The next section examines the effect of management practices on soil conservation.

Management Practice in Field Crops

Management practices that directly affect the loss of pesticides from corn and sorghum crops are those that reduce runoff and erosion. Recognition of the need for good conservation practices as a means to reduce runoff and erosion has existed a long time. The Universal Soil Loss Equation (USLE), developed by Wischmeier and Smith,[3] is a good example of the importance that cropping practices and erosion control practices have on soil erosion. The equation is used to compute the annual average soil loss (sheet and rill erosion) per unit area (tons/acre/year). The equation is:

$$E = R \cdot K \cdot L \cdot S \cdot C \cdot P$$

where R is the rainfall factor; K is the soil erodibility factor; L is the slope-length factor; S is the slope gradient factor; C is the cropping management factor; and P is the erosion-control practice factor.

For our purposes, the main consideration here are the C and P factors. These factors were built into the equation since it was recognized that management practices used by farmers had a definite, and often significant, effect on soil erosion from their crops. The C factor--cropping management factor--is the ratio of soil loss from a field with specified cropping and management to that from the fallow condition on which the K factor is evaluated. This factor reflects the influence of type of vegetal cover, seeding method, soil tillage, disposition of residues, and general management level. The P factor--erosion-control practice factor--is the ratio of soil loss with contouring, stripcropping, or terracing to that with straight-row farming, up and down slope. This factor represents the effects contouring, contour stripcropping, terracing, and diversion have on soil loss.

To show the relative magnitude of the effects farm management can have on soil loss, Table 31[4] gives the practice values for contouring, contour strippcropping and terracing. Thus, it is evident that if other factors remain the same for a given crop, contour stripcropping, for example, on a slope of 2 to 7%, would reduce soil loss by 75%.

As a further illustration, the Agricultural Research Service[4] published some examples of the use of USLE in watershed planning to show the effect conservation practices can have on soil management. In one of the examples, soil loss from a 280 acre crop of corn is compared under present conditions and future conditions. The present conditions are: (a) continuous corn with residue removed--average yield 70 bu/acre; and (b) cultivated up and down slope. The future conditions are: (a) rotation of wheat, meadow, corn, corn with residue left; and (b) contour stripcropping. All other conditions of soil (Fayette silt loam), slope (8%), and slope length (200 ft) remain constant.

Under the present conditions, the C factor is 0.43 and the P factor is 1.00, while under the future conditions the C factor (reflecting crop rotation) is 0.119 and the P factor (reflecting contour stripcropping) is 0.30. The calculations show that soil loss under present conditions is 41.5 tons/acre/year compared to 3.4 tons/acre/year under future conditions. The effects of good management shown by this example are self-evident.

Table 31. "P" VALUES FOR CONTOURING, CONTOUR STRIPCROPPING, AND TERRACING

Land slope (%)	Contouring	P values contour stripcropping	Terracing a/	Terracing b/
2.0 to 7	0.50	0.25	0.50	0.10
8.0 to 12	0.60	0.30	0.60	0.12
13.0 to 18	0.80	0.40	0.80	0.16
19.0 to 24	0.90	0.45	0.90	0.18

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a/ For erosion-control planning on farmland.

b/ For prediction of contribution to off-field sediment load.

Source: "Procedure for Computing Sheet and Rill Erosion on Project Areas," Technical Release No. 51, Soil Conservation Service, U.S. Department of Agriculture (1972).

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An additional example will help illustrate the importance of cropping practice. Soil losses are the greatest when a field is fallow or bare of cover and are reduced as crops are introduced, and as good cropping practices are used. Table 32[5/] illustrates that a cropping practice of continuous corn gave a soil loss of 19.72 tons/acre/year, and rotation of corn, wheat, and clover gave a loss of 2.78 tons/acre/year. There was a corresponding reduction of runoff as a percentage of rainfall.

Obviously, good management in farm operations is important to the reduction of runoff and erosion. However, there is evidence that good management practices are not used throughout agriculture, and that a large potential for further erosion and runoff control of pesticides in crop soils exists today.

In support of the statement that good management practices are wanting, the following data were obtained from a report written by Shrudar Lin:[6/]

> "The total land area in Illinois is about 35.7 million acres; 24.4 million acres are used for tilled crops. In 1967, about 72% of the tilled soil was devoted to corn and soybeans. An inventory of conservation needs indicates that 66% of this crop land acreage is not adequately treated. The most needed conservation practices, with the percent of crop land involved are:
>
> | | |
> |---|---|
> | Contour farming | 10.5% |
> | Terraces or diversion | 10.5% |
> | Cover crops | 20.0% |
> | Crop rotation | 9.0% |
> | Drainage | 13.0% |
>
> A review of the acreage of crop land on a county basis showed that 77 of the 102 counties in Illinois required additional treatment on 60% or more of the total crop land within their boundaries."

The method farmers use (or do not use) to rotate crops, till the soil, practice erosion control and apply good crop management techniques in general to their crops has a profound effect on the runoff and erosion experienced in agriculture. Since pesticides (as will be shown in subsequent sections) are transported from crops in both runoff water and sediment losses, it is necessary that good management is used to reduce these chemical losses into the environment. Though some of the nation's farms do minimize chemical losses through conservation, others do not. Those

Table 32. EFFECTS OF DIFFERENT CROPPING SYSTEMS ON RUNOFF AND EROSION

Cropping practice	Soil loss (tons/year)	Runoff (% of rainfall)
Continuous bluegrass	0.34	12.0
Rotation of corn, wheat, clover	2.78	13.8
Continuous wheat	10.09	23.3
Continuous corn	19.72	29.4
Fallow	41.65	30.7

Source: "Agricultural Pollution of the Great Lakes Basin," Report by Canada and the United States, U.S. Environmental Protection Agency, Water Quality Office (1971).

that do not must be considered inefficient in the use of pesticides in this respect.

Pesticide Losses in Runoff and Soil Erosion

Pesticides applied to crops are subject to transport away from the crop in runoff water and sediment. A number of studies have been conducted to substantiate that losses do occur, and several of these studies are presented in Appendix B. Other studies are in progress to determine the magnitude of these losses, and better statistics should be available in the future to quantify these losses. After presentation of the studies the quantities of pesticides in runoff and soil erosion are estimated.

In order to ultimately determine the quantities of pesticides transported from the soil of crops, two approaches are possible. The first is to determine the concentration of pesticides in both the runoff and sediment, determine the volume of runoff and weight of sediment transported from each crop, and then multiply the concentrations times the volume or weight to arrive at the total pesticide loss. The second method is to determine the pesticide loss from the crops as a percent of the quantity applied, determine the amount of pesticides applied to the crops, and then multiply the percentage loss times the amount applied to arrive at the total pesticide loss.

This study examines both methods. There are, however, difficulties involved in either approach, and these problems can be summarizes as follows:

1. There is no current method of accurately determining the amount of runoff or the amount of sediment lost from crops. Use of the USLE is the best method to predict soil erosion, but the six variables in the equation vary widely throughout the United States. Annual runoff statistics are available from the U.S. Geological Survey,[7] but these statistics cover all land areas, not just crops.

2. The concentrations of pesticides in sediment and runoff vary with pesticide characteristics, such as solubility, volatility, polarity, and degree of association; and with soil characteristics such as moisture, soil acidity, porosity, and bacterial population, just to name a few parameters.

3. The investigations conducted on pesticide concentrations in runoff and sediment that were found in this study are finite. They each apply to circumstances in which many of the variables involved are fixed (such

as soil slope, soil type, rainfall, etc.). Obviously, the results of such studies cannot be applied to a general case for all croplands without some degree of error.

The three difficulties cited above are the major ones and they are insurmountable with regard to quantifying the crop pesticide losses with accuracy. However, the objective of this study is to quantify the losses and an attempt to do so is made. Even if reasonable estimates are later deemed impossible to make, the reason can be determined from the difficulties encountered along the way.

Only runoff is considered in the first method cited above since there are two methods (discussed later) that can be used to make a gross estimate of the amount of runoff from the study crops. On the other hand, any estimate of total soil loss from the study crops would be so gross that it would be useless. Until a method for calculating the amount of soil loss from croplands is found, the use of the first method for determining pesticide losses in soil erosion (that is, concentration of pesticide in soil times weight of soil lost) is not feasible.

Appendix B gives the field studies on pesticide runoff after application obtained from the literature. It is divided into two sections, although some of the field investigations cited appear in both sections. The first section presents concentrations of pesticides found in runoff waters from croplands. The second section presents total quantities of pesticides lost from crops as a percent of the quantity applied, for both runoff and sediment transport considered as a whole.

The above studies do not investigate all of the pesticides that are of major importance to the three study crops. The major herbicides are: (a) atrazine; (b) propazine; (c) propachlor; (d) alachlor; (e) 2,4-D; and (f) butylate. The major insecticides are: (a) aldrin; (b) bux; (c) carbofuran; (d) phorate; (e) diazinon; (f) carbaryl; (g) parathion; and (h) methyl parathion. Since not all these pesticides have been studied, it is necessary to estimate the concentrations each would have in runoff.

Before doing this, however, we must introduce an important point. A major aspect of the problem of quantifying the losses is the timeliness of the runoff experience. Figure 11[8]/ shows the persistence of selected pesticides in soils. These data show the time required for a 75 to 100% reduction in the initial amount of pesticide applied under normal soil conditions using normal application rates. Therefore, this fact is considered when quantifying the pesticide losses, and the assumption is made that when the time period that a pesticide remains in the soil after application exceeds the value given in Figure 11, the pesticide losses are negligible.

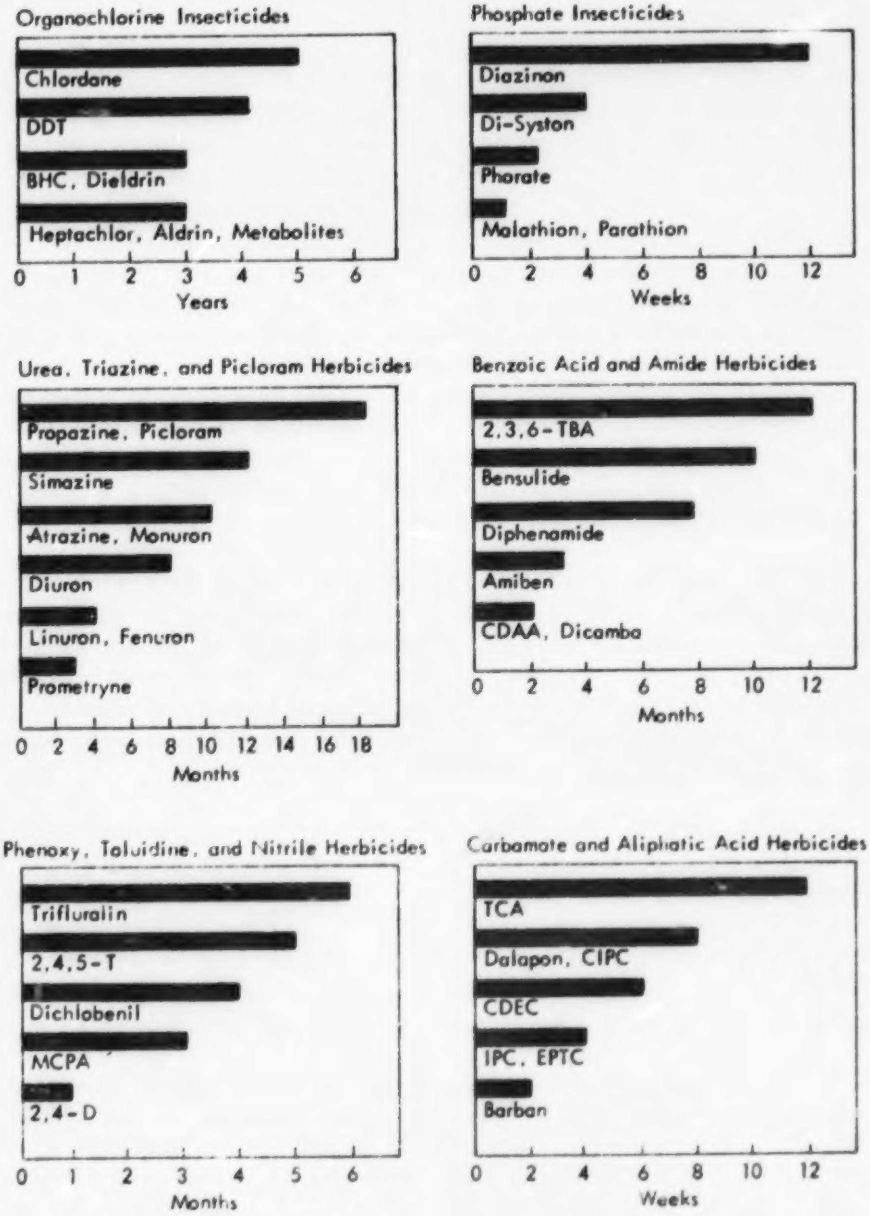

Figure 11. Persistence of individual pesticides in soils.

Source: Kearney, P. C., and Helling, C.S., "Reactions of Pesticides in Soils," Residue Reviews, Vol. 25 (1969).

Not all of the important pesticides are given in Figure 11. However, with the use of other references, Table 33 is constructed to show the maximum length of time during which runoff and erosion losses occur for each pesticide.

Alachlor and butylate were not investigated in the field studies presented in Appendix B. Alachlor and propachlor are both acetanilides made by the same company and are assumed to be present in runoff in similar concentrations and to have the same soil persistence. Butylate is a thiocarbamate and is chemically dissimilar from the other herbicides studied. Therefore, butylate is excluded from further consideration.

The insecticides aldrin, bux, carbaryl, phorate, parathion, and methyl parathion were not investigated in the studies presented in Appendix B. Aldrin is a highly chlorinated cyclic hydrocarbon with a very low solubility (0.027 ppm)[9] and is chemically similar to both dieldrin and endrin, whose solubilities are 0.86 ppm and insoluble,[9] respectively. (Solubilities are compared since these chemicals are the only ones studied whose solubities seem to make a difference. All the other chemicals had solubilities well above the concentrations found in the runoff.) Aldrin will be assumed to have concentration values similar to endrin and dieldrin. Parathion and methyl parathion are organophosphorus compounds similar to diazinon and will assume the same values. Bux, carbaryl, and phorate are dissimilar to the other insecticides studied, and will not be considered, since any estimation would be a mere guess.

Table 34 is constructed from the information presented in Table 33 and in the field studies cited in Appendix B. It presents the estimated concentration of pesticide that can be expected in runoff water for a runoff event occurring within a specified time interval after the pesticide is applied.

The amount of loss from ground runoff and soil erosion depends upon rate of application, type of soil surface, and depth of application. These factors are taken into account, and Table 35 gives the loss of the pesticides studied in Appendix B as a percent of the total applied. Unfortunately, this table is not entirely representative of possible losses since important factors such as soil type, soil slope, amount of rainfall, and occurrence of rain immediately after application are important factors, also. However, this table should give a good approximation to the losses to be expected when using these pesticides.

The next step is to construct a table similar to Table 34, showing the expected range of values for the percentage loss with respect to the time the pesticide has remained in the soil. Since the studies in Appendix B were limited to only six of the important pesticides, some assumptions must be made.

Table 33. PERIOD OF TIME AFTER APPLICATION IN WHICH PESTICIDES ARE SUBJECT TO RUNOFF LOSSES

Herbicide	Time (weeks)	Insecticide	Time (weeks)
Alachlor	Unavailable	Aldrin	156
Atrazine	48	Carbofuran	10[b]
2,4-D	4	Diazinon	12
Propachlor	6[b]	Methyl parathion	2[a]
Propazine	78	Parathion	1

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a/ Source: "The Effects of Agricultural Pesticides in the Aquatic Environment, Irrigated Croplands," San Joaquin Valley, Office of Water Programs, Environment, American Chemical Society, Washington, D.C.

b/ Source: Pesticide Manual, Second Edition, British Crop Protection Council (1971).

Table 34. ESTIMATED CONCENTRATION OF PESTICIDES IN RUNOFF[a/]

Pesticide	Time in soil (weeks)		Concentration in runoff (ppb) Low	Typical	High
Herbicides					
Alachlor	1	(First storm)	100	500	800
	1-6		10	50	100
Atrazine	1	(First storm)	1,000	1,500	2,500
	1-48		10	50	200
2,4-D	1	(First storm)	1,000	1,800	2,500
	1-4		10	50	100
Propachlor	1	(First storm)	100	500	800
	1-6		10	50	100
Propazine	1	(First storm)	1,000	1,500	2,500
	1-78		10	50	100
Insecticides					
Aldrin	156		1	2	10
Carbofuran	1	(First storm)	1,000	2,000	3,000
	10		10	50	100
Diazinon	12		5	10	20
Methyl parathion	2		5	10	20
Parathion	1		5	10	20

[a/] This table reflects the fact that the largest concentrations in runoff occur with the first rainstorm. If a storm should occur within the first week after application, the concentration of pesticide in the runoff from that storm is so indicated. The second set of values given for each pesticide with a first storm value indicate the estimated concentrations in each runoff event occuring after the first week. Aldrin, diazinon, methyl parathion, and parathion have small concentrations even during the first week after application.

Table 35. SUMMARY OF PESTICIDE LOSSES DETERMINED FROM FIELD STUDIES IN APPENDIX B

Pesticide	Type of soil surface	Depth of application (in.)	Rateof application (lb/acre)	Loss as % of total applied
Carbofuran	Plowed, planted	3	4.83	0.9
	Furrowed, planted	2	3.71	0.5
	Furrowed, planted	2	2.77	1.9
Dieldrin	Plowed, planted	3	5.0	0.007[a]
	Cultipacked, planted	3	5.0	2.2[b]
Picloram	Plowed	Unknown	5.0	0.06[c]
Diazinon	Ridged, planted	1-2	1.0	Insignificant[d]
	Contoured, planted	1-2	1.0	0.1[d]
Propachlor	Contoured, planted	Surface	4.0	Insignificant[d]
	Ridged, planted	Surface	4.0	Insignificant[d]
	Contoured, planted	Surface	6.0	3.1
	Ridged, planted	Surface	6.0	Insignificant[d]
Atrazine	Contoured, planted	Surface	2.0	8.2
	Ridged, planted	Surface	2.0	3.9
	Contoured, planted	Surface	3.0	16.0[e]
	Ridged, planted	Surface	3.0	2.7[e]
	Smooth	Surface	3.0	2.0 to 7.3
	Smooth	Surface	3.0	2.5
2,4-D Butyl ester	Unknown	Unknown	2.2	13
2,4-D Amine ester	Unknown	Unknown	2.2	4

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[a] No soil erosion involved, just runoff water.
[b] Due to soil erosion.
[c] Water runoff only.
[d] No heavy rains during year of application.
[e] Heavy rain just 7 days after application removed ~ 90% of total loss.

Alachlor, butylate, and propazine were not investigated. Propazine and atrazine are both triazines and have similar properties, so the losses of atrazine are assumed to be representative of those for propazine as well. Alachlor and propachlor are both acetanilides, and alachlor is assumed to be similar to propachlor in soil and runoff losses. Butylate is unrelated to any of the pesticides previously discussed and is excluded from further consideration.

Aldrin, methyl parathion, and parathion were not studied. Aldrin is a highly chlorinated cyclic hydrocarbon similar to dieldrin, and values of losses for aldrin are assumed to be the same as for dieldrin. Methyl parathion and parathion are organophosphorus compounds similar to diazinon, and are given the same values obtained for diazinon.

Making the above assumptions and with the information presented in the field studies, Table 36 is constructed to show the expected percentage loss of each pesticide from the soil to which it is applied. This table is used later to quantify the pesticide losses from the study crops.

Any estimates on the amount of pesticide lost due to runoff and erosion must take into account the importance of the time element involved. When storms do not occur within a week or two of application, the amount of pesticide loss is substantially reduced.

Estimated Runoff from the U.S. Corn and Sorghum Crops - Quantities

The quantification of runoff is done by two methods in order to see how the predictions compare. The first method uses the average annual runoff map constructed by the U.S. Geological Survey[7/] in combination with the average seasonal runoff map[10/] for the spring months of April, May and June. These maps are used to estimate the total crop runoff from both corn and sorghum crops during those months. The second method uses maps[11/] showing the mean total precipitation (inches) by state climatic divisions, for each of the months of April, May and June. The rainfall statistics given on the maps are used to calculate the amount of runoff by assuming a certain percentage of the rainfall runs off the crops. Each method is described in detail below.

Method 1 - Average Seasonal Runoff - Average annual runoff is a variable phenomenon and is determined on the basis of continuing measurements of stage and discharge at 8,400 gauging stations throughout the U.S. They collect data that are analyzed and plotted by the U.S. Geological Survey to produce the annual average runoff map. This map is shown as Figure 12.

Table 36. PERCENT PESTICIDE LOSS FROM CROPS AS A PERCENT OF THE TOTAL AMOUNT APPLIED[a]

Pesticide	Time in soil (weeks)	Loss due to runoff and erosion (%)		
		Low	Typical	High
Herbicides				
Alachlor	1 (First storm)	0.5	1.0	3.0
	1-4	0.0	0.5	1.0
Atrazine	1 (First storm)	0.5	2.0	5.0
	1-48	0.5	1.0	2.0
2,4-D	1 (First storm)	1.0	3.0	5.0
	1-4	0.05	0.1	0.3
Propachlor	1 (First storm)	0.5	1.0	3.0
	1-4	0.0	0.5	1.0
Propazine	1 (First storm)	0.5	2.0	5.0
	1-78	0.5	1.0	2.0
Insecticides				
Aldrin	1-156	0.5	1.0	2.0
Carbofuran	1 (First storm)	0.5	1.0	2.0
	1-10	0.0	0.1	0.2
Diazinon	1 (First storm)	0.01	0.05	0.1
	1-12	Negl.	Negl.	Negl.
Methyl parathion	2	0.01	0.05	0.1
Parathion	1	0.01	0.05	0.1

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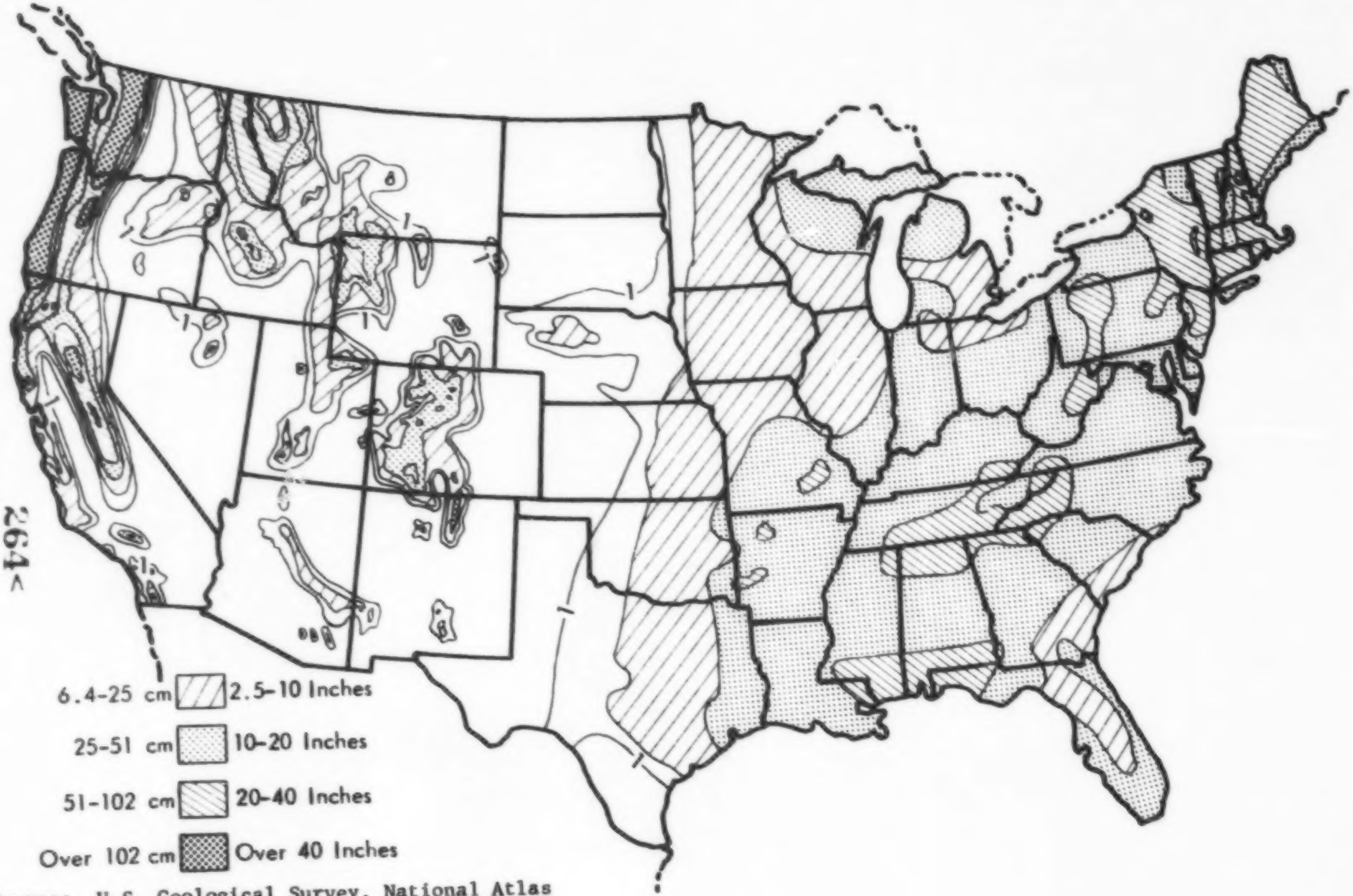
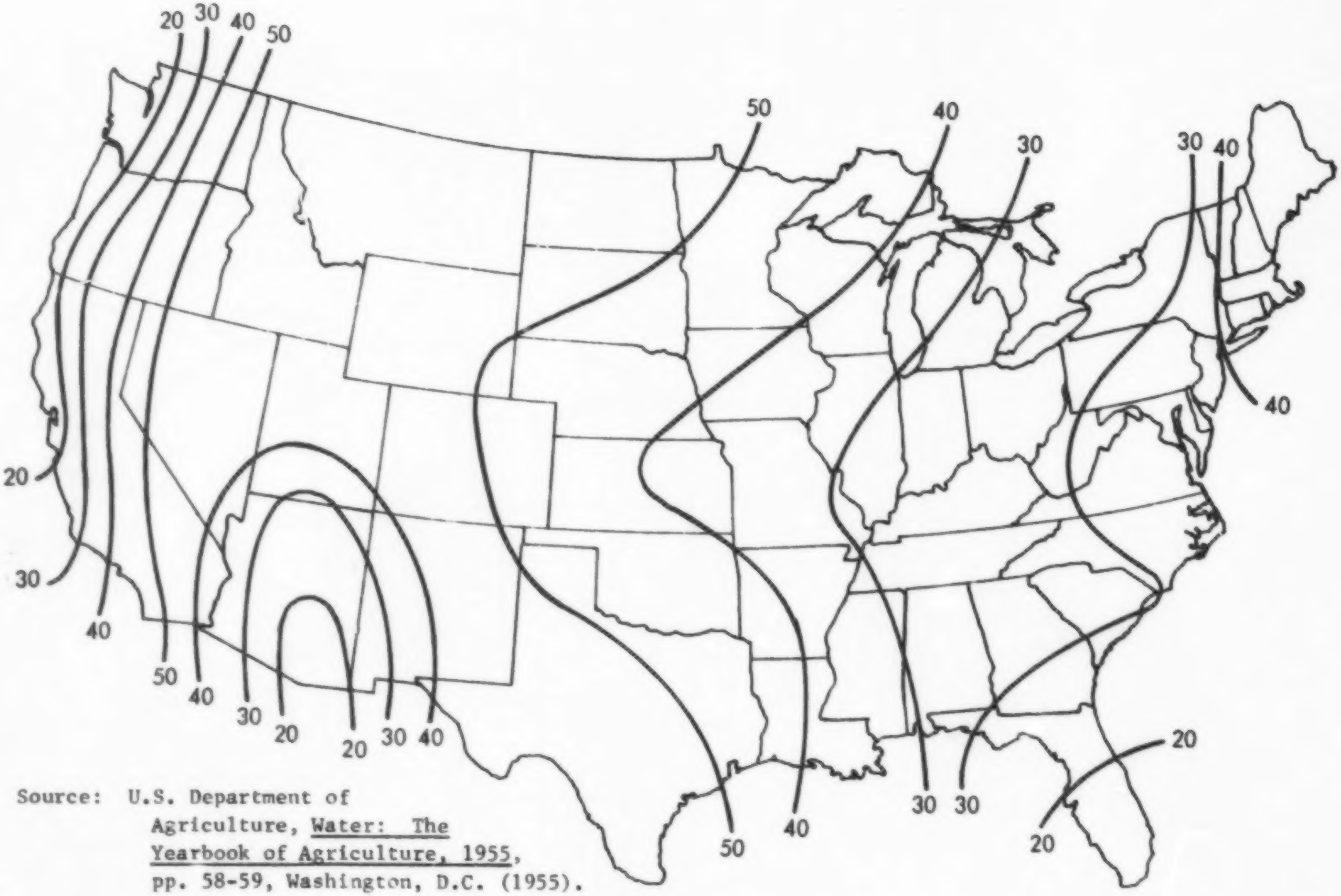
[a] This table reflects the fact that the heaviest losses occur with the first rainstorm. If a storm should occur within the first week after application, the amount of pesticide lost in that storm is so indicated. The second set of values given for each pesticide with a first storm value indicate the percent loss expected for the time period indicated. If a storm does not occur within the first week, these values are used. If a storm does occur in the first week, the total loss for the entire time period is the sum of the two values. Timing of the storm has no appreciable affect on aldrin, methyl parathion, or parathion.


6.4-25 cm ▨ 2.5-10 Inches
25-51 cm ▒ 10-20 Inches
51-102 cm ▨ 20-40 Inches
Over 102 cm ▩ Over 40 Inches
1

Source: U.S. Geological Survey, National Atlas of the United States of America, Washington, D.C. (1970).

Figure 12. Average annual runoff.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Source: U.S. Department of
Agriculture, Water: The
Yearbook of Agriculture, 1955,
pp. 58-59, Washington, D.C. (1955).

Figure 13. Average seasonal runoff, percent of total annual runoff, spring months--April, May, and June.

The period April through June is the most critical in this study. The vast majority of herbicides and insecticides applied to corn and sorghum are applied at the beginning of this period, and since the greatest pesticide losses occur soon after application, the amount of runoff in this period is critical in determining the amounts of pesticide lost from this mechanism.

To calculate the amount of runoff in April, May and June, the map showing the average seasonal runoff, percent of total annual runoff, spring months--April, May and June is used. This map is shown as Figure 13. Multiplying the percentages given on this map times the annual runoff statistics provided by Figure 12 gives the runoff for the 3-month period.

Unfortunately, these maps provide runoff for the entire U.S. land area, not just the agricultural. Some areas, such as pastures, forests, and grassland, have very low runoff values, while others, such as fallow or bare ground, have high runoff values. Since the topography and land use vary widely across the country, a range of values is given for the runoff predictions from the two crops.

Tables 37 and 38 show the runoff predictions for corn and sorghum, respectively. The acreages are obtained from Appendix C, Figures C-2 and C-3; the annual runoff values (inches) are estimated from Figure 12; and the percentage runoff experienced for the months of April, May and June are taken from Figure 13.

Method 2 - Rainfall Statistics - The rainfall statistics maps provided by the U.S. Department of Commerce are shown in Figures 14, 15, and 16.[11] These statistics are more accurate for our purposes than the runoff statistics. However, the error in this method develops when the amount of rainfall is correlated with the amount of runoff resulting from that rainfall. Runoff, as in the case of erosion, varies widely within the total crop and depends upon many of the same factors that affect erosion.

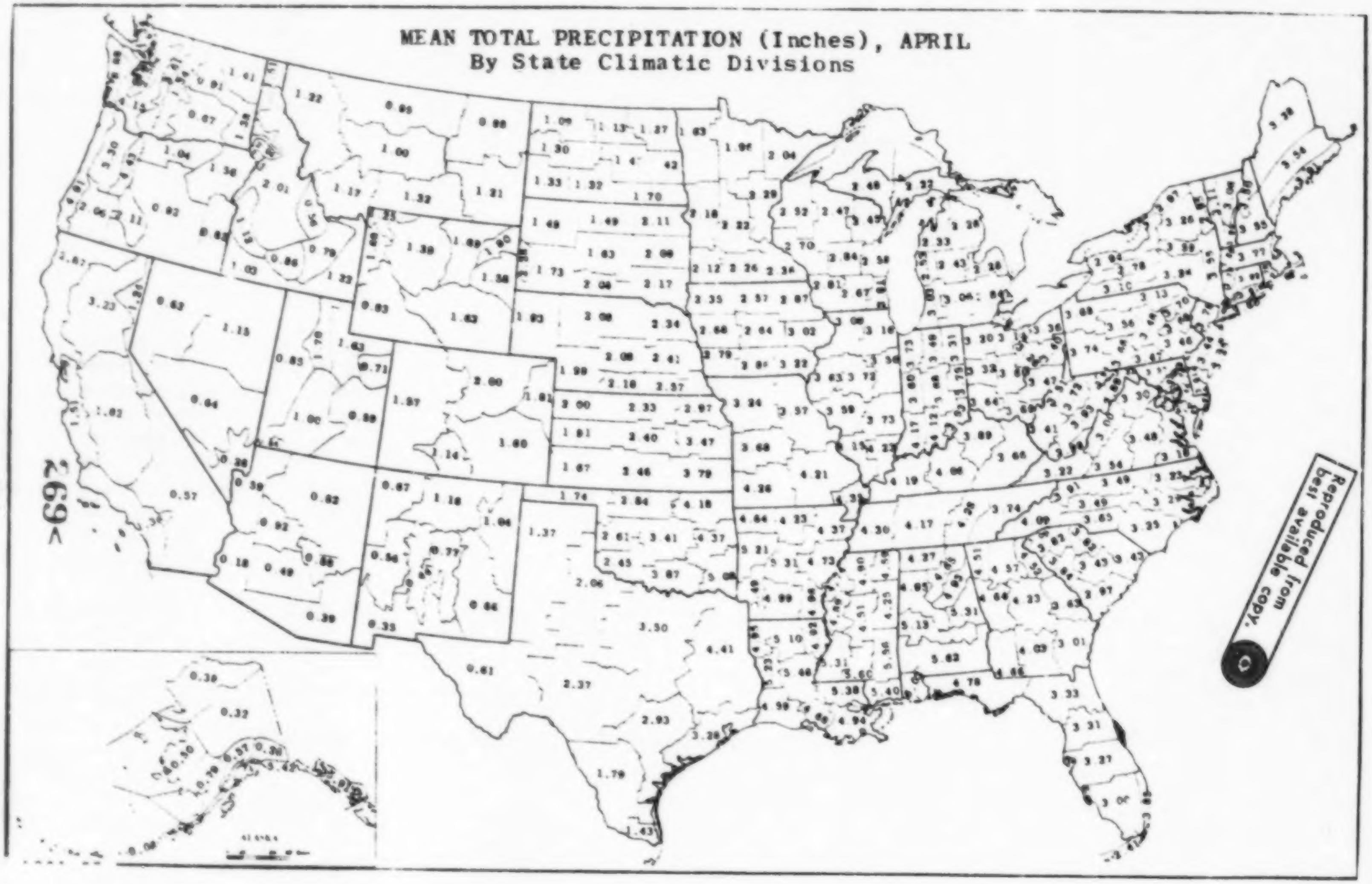
To predict the amount of runoff, it is necessary to calculate the percent of rainfall that runs off the two crops. Again we are faced with a gross estimate since cropping practices, soil types, soil slopes, etc., vary widely over the crops. Table 32 (p.111), shows that the percentage of rainfall that runs off a crop varies with the cropping practice used, and this table provides some gross estimates of the percentages involved. The amount of runoff as a percentage of rainfall is 30.7% for fallow ground; 29.4% for continuous corn; and 12.0% for continuous bluegrass.

Table 37. ESTIMATED CORN CROP RUNOFF IN APRIL, MAY, AND JUNE (METHOD ONE)

Region	Acres (000)	Annual runoff (in.)		Spring runoff (%)	Spring runoff acre-inches (millions)		Spring runoff (10^{10} lb)	
		Low	High		Low	High	Low	High
Northeast	3,600	7	15	35	8	19	180	430
Lake States	12,000	4	10	45	22	54	500	1,220
Corn Belt	35,400	7	15	35	87	186	1,970	4,210
Northern Plains	12,000	1	2	45	5	11	110	250
Appalachian	4,700	10	25	30	14	35	320	790
Southeast	3,400	10	20	30	10	20	230	450
Delta States	400	4	8	35	0.6	1	15	25
Southern Plains	800	1	2	50	0.4	0.8	10	20
Mountain	1,100	1	2	50	0.6	1	15	25
Pacific	500	1	2	35	0.2	0.4	5	10
Total	73,900				147.8	328.2	3,355	7,430

Table 38. ESTIMATED SORGHUM CROP RUNOFF IN APRIL, MAY, AND JUNE (METHOD ONE)

Region	Acres (000)	Annual runoff (in.)		Spring runoff (%)	Spring runoff, acre-inches (millions)		Spring runoff $(10^{10}$ lb)	
		Low	High		Low	High	Low	High
Northeast	-	-	-	-	-	-	-	-
Lake States	-	-	-	-	-	-	-	
Corn Belt	1,100	55	15	35	1.9	5.8	43	131
Northern Plains	8,000	1	3	40	3.2	9.6	72	217
Appalachian	400	10	25	30	1.2	3.0	27	68
Southeast	300	10	20	30	0.9	1.8	20	40
Delta States	600	10	20	35	2.1	4.2	48	95
Southern Plains	8,800	1	2	50	4.4	8.8	100	200
Mountain	1,200	1	2	40	0.5	1.0	11	23
Pacific	300	1	2	40	0.1	0.2	2	4
Total	20,700				14.3	34.4	323	778



MEAN TOTAL PRECIPITATION (Inches), APRIL
By State Climatic Divisions

Figure 14. Mean total precipitation (inches), April, by state climatic divisions.

Source: U.S. Department of Commerce, Climatic Atlas of the United States, p. 45 (1968).

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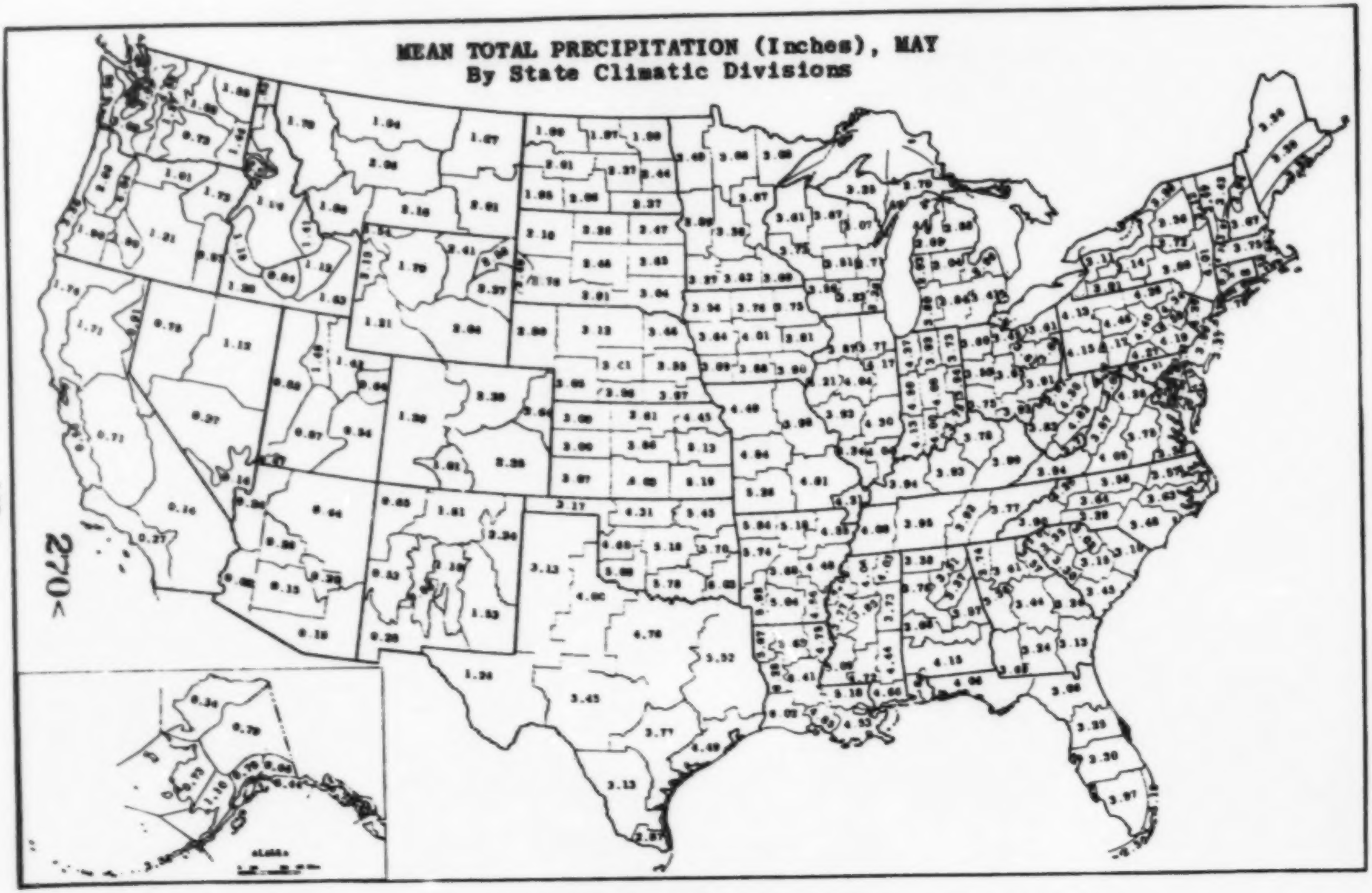

MEAN TOTAL PRECIPITATION (Inches), MAY
By State Climatic Divisions

Figure 15. Mean total precipitation (inches), May, by state climatic divisions.

Source: U.S. Department of Commerce, Climatic Atlas of the United States, p. 46 (1968).

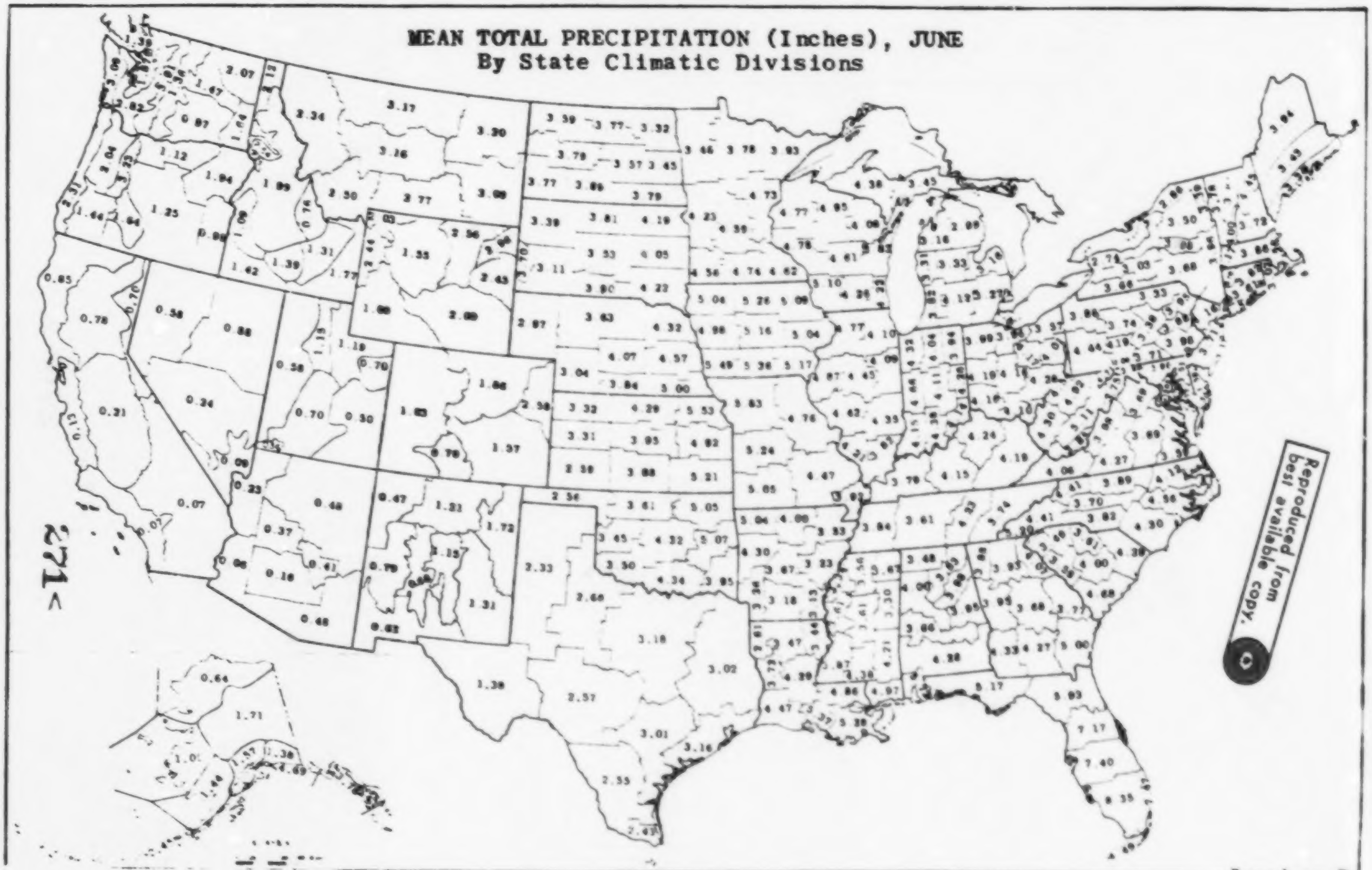
MEAN TOTAL PRECIPITATION (Inches), JUNE
By State Climatic Divisions

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Figure 16. Mean total precipitation (inches), June, by state climatic divisions.

Source: U.S. Department of Commerce, Climatic Atlas of the United States, p. 46 (1968).

For our estimation, the high value of the percent runoff on the crops is assumed to be 30%. The low value is assumed to be below that of continuous bluegrass, and is placed at 10%. These values place the limits in a wide enough range to reduce the error of the estimation to a minimum.

Tables 39 and 40 are constructed to show the estimated runoff from the corn and sorghum crops using rainfall statistics and estimates of the amount of runoff that accompanies the rainfall. Average rainfall over each region is taken from Figures 14, 15, and 16.

Both Methods 1 and 2 use rather crude methods to estimate the runoff quantities from the crops, but no other methods are available to make more reasonable estimates that do not involve a massive research effort which is outside the scope of this study. The values of the runoff estimates just presented are compared in the next section.

Methods 1 and 2 Compared - The information developed by the two methods for predicting the amount of runoff from corn and sorghum crops is now compared. Table 41 compares the estimates developed by each method and shows that the runoff values predicted by Method 2 are less than those predicted by Method 1 for the corn crop, while the opposite is true for the sorghum crop. This arises from the fact that in all regions except the Southern and Northern plains, the amount of runoff is higher in Method 1 than Method 2. These two regions show the opposite effect. Since the acreage in these regions is insignificant in the corn crop, the total values of runoff predicted by Method 1 are higher. However, in the sorghum crop these two regions are dominant in sorghum production and make the total runoff values higher for Method 2 than for Method 1.

The Northern and Southern plains deviate from the pattern since the runoff in these two regions shown on the annual runoff map is very low compared to the rest of the nation, while the spring rainfall is only slightly lower in these two regions than in the others around the remainder of the U.S. (particularly in May and June). Whether the runoff, as a percentage of rainfall, is lower for the sorghum crop in these two regions than in the other regions is indeterminate. Without further information, this conflict defies evaluation.

The two methods agree reasonably well considering the gross values used in each method. The approach taken here to estimate runoff is difficult to improve upon unless a mountain of statistics is available to the researcher who attempts to make such an estimate. Even then, variables such as cropping practices and rainfall patterns constantly change, and make calculations of runoff an estimation in the final analysis. This is the reason a range of values has accompanied each estimation made to this point.

Table 39. ESTIMATED CORN CROP RUNOFF IN APRIL, MAY, AND JUNE (METHOD TWO)

Region	Acres (000)	Rain, acre-inches (millions)			Pounds rain (10^{10})			Runoff (10^{10} lb)							
								% Runoff		April		May		June	
		April	May	June	April	May	June	Low	High	Low	High	Low	High	Low	High
Northeast	3,600	12	15	14	270	340	320	10	30	27	81	34	102	32	96
Lake States	12,000	28	39	50	630	880	1,130	10	30	63	189	88	264	113	339
Corn Belt	35,400	118	139	164	2,670	3,140	3,710	10	30	267	801	314	942	371	1,113
Northern Plains	12,000	25	37	44	570	840	1,000	10	30	57	171	84	252	100	300
Appalachian	4,700	17	19	21	380	430	480	10	30	38	114	43	129	48	144
Southeast	3,400	14	12	15	320	270	340	10	30	32	96	27	81	34	102
Delta States	400	1	1	1	20	20	20	10	30	2	6	2	6	2	6
Southern Plains	800	2	3	4	50	70	90	10	30	5	15	7	21	9	27
Mountain	1,100	2	2	2	50	50	50	10	30	5	15	5	15	5	15
Pacific	500	1	1	1	20	20	20	10	30	2	6	2	6	2	6
Total	73,900	220	268	316	4,980	6,060	7,160			498	1,494	606	1,818	716	2,148

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Table 40. ESTIMATED SORGHUM CROP RUNOFF IN APRIL, MAY, AND JUNE (METHOD TWO)

Region	Acres (000)	Rain, acre-inches (millions)			Pounds rain (10^{10})			Runoff (10^{10} lb)							
								% Runoff		April		May		June	
		April	May	June	April	May	June	Low	High	Low	High	Low	High	Low	High
Northeast	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lake States	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Corn Belt	1,100	4	5	5	90	110	110	10	30	9	27	11	33	11	33
Northern Plains	8,000	19	29	32	430	660	720	10	30	43	129	66	198	72	216
Appalachian	400	1.5	1.5	1.5	30	30	40	10	30	3	9	3	9	4	12
Southeast	300	1.3	1.1	1.2	30	30	30	10	30	3	9	3	9	3	9
Delta States	600	3.0	3.5	2.7	70	80	60	10	30	7	21	8	24	6	18
Southern Plains	8,800	22	34	25	500	770	570	10	30	50	150	77	231	57	171
Mountain	1,200	1.3	1.5	1.4	30	30	30	10	30	3	9	3	9	3	9
Pacific	300	0.5	0.1	0.1	10	2	2	10	30	1	3	-	1	-	1
Total	20,700	52.6	75.7	69.0	1,190	1,712	1,562			119	357	171	514	156	469

Table 41. COMPARISON OF METHODS 1 AND 2

Corn crop

Region	Method 1 spring runoff (10^{10} lb) Low	Method 1 spring runoff (10^{10} lb) High	Method 2 spring runoff (10^{10} lb) Low	Method 2 spring runoff (10^{10} lb) High
Northeast	180	430	93	279
Lake States	500	1,220	264	792
Corn Belt	1,970	4,210	952	2,856
Northern Plains	110	250	241	723
Appalachian	320	790	129	387
Southeast	230	450	93	279
Delta States	15	25	6	18
Southern Plains	10	20	21	63
Mountain	15	25	15	45
Pacific	5	10	6	18
Total	3,355	7,430	1,820	5,460

Sorghum crop

Region	Method 1 Low	Method 1 High	Method 2 Low	Method 2 High
Northeast	-	-	-	-
Lake States	-	-	-	-
Corn Belt	43	131	31	93
Northern Plains	72	217	181	543
Appalachian	27	68	10	30
Southeast	20	40	9	27
Delta States	48	95	21	63
Southern Plains	100	200	184	552
Mountain	11	23	9	27
Pacific	2	4	1	5
Total	323	778	446	1,340

The next section brings all of the information previously developed into practical application in estimating the quantities of pesticides lost from the corn, sorghum, and apple crops in the year 1971.

Estimated Pesticide Losses from the U.S. Corn, Sorghum, and Apple Crops (1971) - Quantities

The previous discussions involving runoff and erosion should alert the reader to the fact that the values used were estimates based on limited information. All of the studies performed on pesticide concentrations in runoff and erosion events were conducted under limited circumstances and certainly cannot be taken as fact under all circumstances. The runoff predictions were based on average rainfall over a period of 25 years (1931 to 1955), and the percent of runoff accompanying the rainfall was predicted on average values for crop runoff. All of these estimates must be considered rather gross and can only be considered estimates.

These estimates, however, are not unrealistic since a range of values is given with the realization that a singular value is impossible to arrive at with confidence. No method exists today to accurately predict the quantities of runoff and erosion experienced on such a diversified area as the corn or sorghum crop. Since cropping practices vary widely, and these practices have a significant effect on runoff and erosion, only an intensive effort to gather pertinent data and statistics on the relevent factors affecting the quantities of erosion and runoff in agriculture would allow the accurate analysis of the problem dealt with here.

This points out an important fact. There is a great deal of information on the concentrations of pesticides in soil and in water. However, these facts are of little value in quantifying pesticide losses in runoff and soil erosion from crops since there is no accurate method of quantifying the amount of runoff and soil losses actually occurring over a wide area. Any investigations into the problem of quantities of pesticides lost from crops must determine the losses as a percentage of the amount applied, since quantities of pesticides applied to crops are more easily determined and documented than are amounts of runoff and erosion. Some of the studies presented in Appendix B have done this and are valuable in our analysis. The vast array of statistics on concentrations in soil and water are of little use in the type of analysis attempted here.

The approach of using concentrations was attempted to determine if a reasonable estimate could be made, but apparently the quantification of runoff and erosion is not now possible. Therefore, only estimates based on the pesticides applied to the crops, using the second approach, are used. Data are more limited on the loss of pesticides as a percentage of the amount applied, but it is the only reasonable approach that can be taken with the information currently available.

For the convenience of presentation, the estimates for pesticide losses due to runoff and erosion from the U.S. corn, sorghum, and apple crops (1971) are discussed in the following subsections: (a) herbicides; (b) insecticides; (c) fungicides; and (d) other pesticides.

Herbicides - In 1971, herbicide use in apple orchards amounted to only 197,000 lb active ingredient. The amount of herbicides used in orchards was negligible compared to the amounts used on corn (101,060,000 lb) and sorghum (11,538,000 lb). Therefore, runoff losses of herbicides from apple orchards are negligible, and only the corn and sorghum crops are dealt with below.

The estimation for the amount of herbicide loss from the corn and sorghum crops requires two types of information: (a) the percent herbicide loss in runoff and soil erosion as a percent of the amount applied; and (b) the amount of herbicide applied to the crop. The percent loss is given in Table 36 (p.120) for five herbicides, and the amount of these herbicides applied to the corn and sorghum crops in 1971 is given in Appendix C, Tables C-2 and C-6, and are listed below:

Herbicide	Amount applied to corn in 1971 (000 lb)	Amount applied to sorghum in 1971 (000 lb)
Alachlor	8,360	20
Atrazine	52,000	4,175
2,4-D	9,144	2,039
Propachlor	21,300	1,433
Propazine	583	2,585

The percentage figures for the amount of herbicide loss in runoff and soil erosion in Table 36 take into account the fact that losses are high if runoff and erosion occur during first week after application. The total herbicide loss as a percent of the amount applied will vary with each crop, depending upon the extent to which runoff and erosion occur in the first critical week after application. The chart below, by calculating the total percent loss of herbicide assuming 20, 40 and 60% of the crop has a runoff event in the first week after application, shows how the percent herbicide loss will vary.

	Percent of crop having a runoff event in first week after application					
	20%		40%		60%	
	Percent herbicide loss in runoff and erosion as a percent of amount applied					
Herbicide	Low	High	Low	High	Low	High
Alachlor	0.1	1.6	0.2	2.2	0.3	2.8
Atrazine	0.6	3.0	0.7	4.0	0.8	5.0
2,4-D	0.25	1.3	0.45	2.3	0.65	3.3
Propachlor	0.1	1.6	0.2	2.2	0.3	2.8
Propazine	0.6	3.0	0.7	4.0	0.8	5.0

The values given for 40% of the crop having a runoff event in the first week after herbicide application are used to calculate the herbicide loss in 1971 on the corn and sorghum crops, since no information was found on this subject as to the actual percentage. If the 40% figure is in error, that is, only 20% of the crop had runoff in the first critical week, then the values estimated are high; and low, if the 60% figure is correct.

Table 42 gives the estimates of the herbicide loss on the corn and sorghum crops (1971) based on the information just presented. The percentage of the total herbicides applied to each crop is merely the amount of each herbicide applied as a percent of the total amount applied--which was 101,060,000 lb on corn, and 11,538,000 lb on sorghum.

This table represents the estimated amount of herbicides lost from the two crops in 1971. More than 90% of the herbicides used on corn are represented in Table 42, and the estimate shows that between 1/2 and 3 million pounds of those herbicides were lost due to runoff and erosion that year. This represents a loss of 0.5 to 3.2% of the selected herbicides (in Table 42) applied to corn. Almost 90% of the herbicides applied to the sorghum crop are represented in Table 42, and the estimate shows that between 60,000 and 350,000 lb of these herbicides were lost due to runoff and erosion that year. This represents a loss of 0.6 to 3.4% of the selected herbicides in Table 42 applied to sorghum. At first glance, 3.2% may seem small, but on the corn crop this percentage represents 3 million pounds of herbicide lost into the environment.

To complete the estimation, the high-low percentages shown above are used for the entire 1971 corn and sorghum crops since the percentages determined above are based on approximately 90% of the total herbicide use on the two crops that year. Extrapolating these figures to all of the herbicides (100%) used gives:

Table 42. ESTIMATED LOSS OF SELECTED HERBICIDES IN RUNOFF AND SOIL EROSION FROM THE U.S. CORN AND SORGHUM CROPS (1971)

Herbicide	Amount applied (000 lb)	Total herbicides used in corn (%)	Lost (%) Low	Lost (%) High	Lost (000 lb) Low	Lost (000 lb) High
		Corn				
Alachlor	8,360	8.3	0.2	2.2	17	184
Atrazine	52,000	51.5	0.7	4.0	364	2,080
2,4-D	9,144	9.1	0.5	2.3	46	210
Propachlor	21,300	20.8	0.2	2.2	43	470
Propazine	583	0.5	0.7	4.0	4	23
	91,387	90.3	-	-	474	2,967
		Sorghum				
Alachlor	20	0.2	0.2	2.2	-	-
Atrazine	4,175	36.2	0.7	4.0	29	167
2,4-D	2,039	17.7	0.5	2.3	10	47
Propachlor	1,433	12.4	0.2	2.2	3	32
Propazine	2,585	22.4	0.7	4.0	18	103
	10,252	88.9	-	-	60	349

Crop	Amount applied, 1971 (000 lb)	Loss (%)		Loss (000 lb)	
		Low	High	Low	High
Corn	101,060,000	0.5	3.2	500	3,200
Sorghum	11,538,000	0.6	3.4	70	390

These figures are the estimates for the herbicide losses from the U.S. corn and sorghum crops (1971) due to runoff and soil erosion. As previously mentioned, the herbicide losses from apple orchards that year are negligible.

Insecticides - Insecticides applied to the three crops amounted to: corn, 25,500,000 lb; sorghum, 5,700,000 lb; and apples, 4,830,000 lb. The information developed in Section III shows that about 70% of the insecticides applied to sorghum, and all of the insecticides applied to apples are foliar applications, while over 90% of the insecticides used on corn crops are soil applications. Since most of the insecticides used on sorghum and apples are foliar applications, and the percentage losses of the major insecticides used on these two crops (shown in Table 36) are insignificant, the quantities of insecticides that are transported from the sorghum and apple crops by runoff are considered to be negligible. Therefore, only insecticides applied to the corn crops are considered in this section.

The information developed in Table 36 (p. 120) concerning the percentage losses of some of the insecticides applied to the soil of corn crops is correlated with the amount of insecticides applied to corn in 1971, as given in Appendix C, Table C-3, and the estimated loss of selected insecticides in the runoff and soil erosion from the U.S. corn crop (1971) is shown in Table 43 (assuming that 40% of the entire corn crop received a runoff event in the first week after insecticide application, as was assumed with herbicides in the previous section). This table shows that between 44,000 and 184,000 lb of the selected insecticides applied to the soil of corn crops were lost due to runoff and erosion, or from 0.3 to 1.3% of the selected insecticides considered.

Slightly more than half of the amount of insecticides used on corn is represented in Table 43. Since the percentage losses are low, the assumption is made that these percentages apply to the entire corn crop as well, without introducing a significant error in the extrapolation. Therefore, the estimates for losses of all insecticides used in corn are:

Table 43. ESTIMATED LOSS OF SELECTED INSECTICIDES IN RUNOFF AND SOIL EROSION FROM THE U.S. CORN CROP (1971)

Insecticide	Amount applied (000 lb)	Total insecticides[a] used in corn (%)	Lost (%)		Lost (000 lb)	
			Low	High	Low	High
Aldrin	7,759	30.4	0.5	2.0	39	155
Carbofuran	2,681	10.5	0.2	1.0	5	27
Diazinon	1,991	7.8	Negl.	0.04	0	1
Parathion	1,329	5.2	0.01	0.1	0	1
Total	13,760	53.9	-	-	44	184

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[a] Amount of each insecticide applied as a percent of the total insecticides applied (25,531,000 lb) to corn in 1971.

Crop	Amount applied, 1971 (000 lb)	Loss (%)		Loss (000 lb)	
		Low	High	Low	High
Corn	25,531,000	0.3	1.3	80	330

These figures represent the insecticide losses from the entire U.S. corn crop (1971) due to runoff and soil erosion. As previously mentioned, the insecticide losses from sorghum and apples that year are negligible.

Fungicides - Fungicides used in 1971 on corn and sorghum were not specified by the U.S. Department of Agriculture report.[12] This report showed that a total of 1,732,000 lb of fungicides (excluding sulfur) were used on the category of crops which included corn, wheat, sorghum, rice, tobacco, soybeans, alfalfa, and sugarbeets, as well as other grains and field crops. Obviously, the use of fungicides on corn and sorghum (compared to herbicide and insecticide usages) was very small, and any losses of fungicides due to runoff and erosion from corn and sorghum are negligible.

Conversely, apples were treated with 7,207,000 lb of fungicides (excluding sulfur). In this case, however, fungicides are applied to the trees and apples, and not to the soil. Since fungicide applications in apple orchards are foliar, little loss from runoff and soil erosion will occur, and the quantities of fungicides that do reach the soil, and subsequently, runoff the orchard, are negligible.

Other Pesticides - The broad category of "other pesticides" includes miticides, fumigants, defoliants, desiccants, rodenticides, plant growth regulators, and repellents. Each of the three study crops received treatment by several of these miscellaneous pesticides, but the quantities involved were small.

Corn was treated with 443,000 lb of miscellaneous pesticides (Appendix C, Table C-4). Fumigants accounted for 386,000 lb of pesticides, and miticides accounted for the remaining 57,000 lb. These quantities are small compared to the insecticides and herbicides used on corn, and losses of these pesticides are negligible.

Sorghum was included in a broad category of crops--the same one mentioned previously under fungicides, excluding corn--that were treated with 3,334,000 lb of miscellaneous pesticides.[12] Fumigants accounted for 3,124,000 lb, or over 90% of the total applied. Again, the use of miscellaneous pesticides on sorghum is considered negligible, and the losses of these pesticides are negligible, also.

Apples were treated with 548,000 lb of miscellaneous pesticides (Appendix C, Table C-11). Miticides accounted for 387,000 lb and plant growth regulators, for 174,000 lb. Miticides are primarily foliarly applied, and do not represent a large quantity of pesticides subject to transport from the orchards by runoff and erosion. Any losses of these pesticides in this manner are negligible.

The next section discusses two miscellaneous discharges of pesticides into the environment; pesticide spills and pesticide disposal.

MISCELLANEOUS PESTICIDE DISCHARGES

Pesticide spills and pesticide disposal both contribute to the inefficient use of agricultural pesticides. Spills are primarily accidental and occur randomly in the use of agricultural pesticides, just as accidents occur randomly in all other areas of life. Though spills are inefficient and potentially dangerous in some cases, they represent a negligible loss when considering the amounts of pesticides used annually to treat crops. Disposal involves both pesticide containers and pesticide residues remaining in the applicator after crop treatment has taken place. Disposal is required in all pesticide operations and the amount of pesticides which are disposed of as residues in both containers and applicators is substantial. However, disposal techniques are controllable since the methods used to dispose of pesticides are the device of man himself. Proper disposal techniques result from education and recognition of the importance good techniques have in keeping the environment clean. Any inefficiencies practiced today in agricultural pesticide disposal can be substantially reduced tomorrow with an effort to disseminate the proper information.

Since spills involve negligible amounts of pesticides and disposal is within man's immediate control, these two subjects did not receive detailed attention in this study. For the sake of completeness, however, these subjects do deserve mention, and are briefly discussed below.

Pesticide Spills

The subject of spillage is covered in this report primarily for the sake of completeness. Spills can occur during handling, loading, or application of pesticides. However, spills are usually accidental and are not considered a wasteful practice unless they involve intentional dumping or avoidable negligence. A brief look at this problem will help to show that it is insignificant in relation to other routes of waste.

Spills can occur in various ways. One way is discharge of the pesticide from a broken, punctured, or defective container. This is generally accidental and not inherently avoidable. Another way is faulty removal of the pesticide from the container to load the pesticide into a mixing tank or into the hopper of the applicator. Again, any spills at this time will be accidental with the exception of excessive drift of dust from granular formulations. Since most pesticides are toxic, common sense dictates that care be exercised to prevent escape of pesticide quantities that could harm the operator during loading. Even in isolated instances where this occurs, the problem is negligible in comparison to the problems of drift that may occur during application.

A third type of spill can occur when loading the spray tanks of an airplane from the nurse tank. The pesticide is transferred by use of an umbilical hose connection, which has check valves on the ends. As long as these hoses are maintained properly there is no leakage. A fourth type of spill may occur when there is leakage from the applicator due to faulty tank valves, lines, or connections. Pesticide losses from these sources do occur, but they will be corrected as soon as they are discovered since pesticides cost money and are toxic substances. A fifth type of spill is one in which the applicator is outside the target area and the operator accidentally or erroneously releases pesticides. This may be considered a spill, but it would obviously be done accidentally or unintentionally.

The examples cited above show the relative insignificance of this route of loss compared to the other factors considered in this report.

Pesticide Disposal

The disposal of pesticides in agriculture has two separate aspects:

1. Disposal of pesticide containers; and

2. Disposal of unused pesticide remaining in the application equipment.

In either case, the original container, tank, or hopper may be empty or partially full. The most serious problem with respect to the quantity of pesticide involved is disposal of surplus spray solutions in the partially full tank or hopper.

The disposal method employed for empty pesticide containers is most often dictated by container size. Most pesticides are sold in bags, 5-gal. cans (metal and plastic), and 55-gal. drums. Approximately 70% of emulsifiable concentrate formulations sold are packaged in 1- and 5-gal. containers, 15% in 30-gal. containers, and 15% in 55-gal. drums; all wettable powder formulations are marketed in bag-weights of 50 lb or less; and granular formulations are packaged in bags weighing 80 lb or less.[13] Due to their size, most 55-gal. drums and a large number of the 30-gal. containers are recycled or disposed of by a commercial disposal service. The remaining containers, approximately 85%, are disposed of by the farmer,* due to the combined factors of smaller container size and inaccessibility of an established disposal site. Disposal of dry formulation containers is usually handled on site. Most commonly, the empty bags are simply thrown in the trash, or burned and the remains taken to a dump site or an approved landfill. Metal and plastic containers are generally rinsed and the rinses added to the spray solution. This procedure aids in reducing not only potentially dangerous residues that may remain in the container but also minimizes the amounts of pesticide that may be lost if the containers were discarded without rinsing. Disposal of these small metal, plastic, and glass containers may follow two routes: (a) the containers may be burned and the remains taken to a dump or landfill; or (b) the containers may be crushed and buried at a site where exposure to man and animals and possible contamination of water supplies is minimal.[14,15]

Empty containers accumulated from small farm operations are most often small, single-trip containers which may be disposed of by the farmer. Disposal of metal, plastic, and glass containers is generally by the rinse/crush/bury method described above. "Empty" bags are usually thrown in the trash, buried, or burned. (It should be noted that special care must be taken not to inhale fumes from open burning of "empty" containers.)[16]

Disposal problems encountered by professional applicators are very similar to those of the large agricultural user in that a large number of empty containers are associated with such operations. Often, "empty" containers tend to build up along runways or in areas where pesticide mixing occurs. Empty 55- and 30-gal. drums are returned to the supplier, taken to community-operated burial landfill sites, or buried on privately owned premises. Disposal procedures employed for small metal, plastic, and glass containers in addition to paper bags parallel those utilized by small farm operations.

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* MRI estimate based on package-size data.

The second aspect of disposal of pesticides in agriculture--emptying the application equipment--has two facets: (a) disposal of the surplus pesticide mixture which may be left in the tank or hopper; and (b) cleaning the empty equipment. The primary disposal problem in agriculture, in terms of quantity, is that of the surplus spray solution. The disposal recommendations for surplus solutions are as follows. Whenever possible, dilute spray solutions should be "carefully applied to the area that has been treated, adjacent borders or safe, protected waste areas. Extreme care must be exercised so that the extra pesticide applied will not result in phytotoxicity, over-tolerance residues or other undesirable results." However, if this method is not feasible, the surplus solution should be run into a shallow holding pit dug in an area where the hazards of percolation or runoff are minimal.[14,15]

Manufacturers recommend cleaning the equipment after each use, or at the end of the day, making disposal of clean-out rinse solutions a frequent problem. Rinse solutions may be applied along with the surplus spray solutions to the previously treated area, adjacent borders, or protected waste area; or may be added to the holding pit with the surplus pesticide solutions. Alternatively, many professional applicators and large farm operators construct sumps (which meet EPA specifications) in which clean-out rinses are placed.

Quantification of pesticides "wasted" in surplus spray solutions, empty containers, and clean-out rinses is not feasible. Disposal of pesticides in cleaning operations is inherent and unavoidable in the agricultural process and, therefore, is not a wasteful practice. Whenever possible, pesticide containers are rinsed several times and the rinses added to the spray solution to minimize pesticide loss. Likewise, residues remaining in paper bags are negligible when compared to pesticide loss via drift, runoff, overapplication, etc. Finally, application equipment operators attempt to accurately calculate the amount of spray solution required for effective treatment. Surplus spray solutions are economic inputs which do not achieve their purpose, i.e., effective pest control. Consequently, losses of pesticides by this route are held to a minimum by economic incentives.

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APPENDIX A

FIELD STUDIES ON PESTICIDE DRIFT DURING APPLICATION

As a result of a review of the literature, a number of field studies on pesticide drift were obtained which are representative of attempts to assess the effects on drift from the type of equipment, type of formulation, and techniques used in agriculture. These studies are listed below in the order they appear in this appendix.

1. Aerial application - drift;

2. Aerial application - time of application and drift;

3. Aerial application - low volume versus ultra low volume sprays;

4. Aerial application - low volume versus ultra low volume sprays;

5. Aerial application - dilute versus low volume sprays;

6. Aerial application and mist-blower application compared;

7. Aerial application and ground application compared;

8. Ground application - effects of an additive, nozzle pressure, and evaporation on drift; and

9. Ground application - spray drift in treating orchards.

A brief discussion and the important findings of each study are given below. The references used to obtain these studies appear at the conclusion of this appendix.

AERIAL APPLICATION - DRIFT

Research has been conducted by Wesley E. Yates and Norman B. Akesson at the University of California, Davis, for over a decade to determine the amount of drift involved in various types of spray applications. They have studied drift of dusts and sprays under actual operating conditions.

Tests[1] conducted over a period of years have included comparisons of the relative quantities of drift for ground applications and aerial applications; for low volume and ultra low volume applications; for large particles and small particles; and for various climatic conditions. The general relationships these factors have to each other, depending on various circumstances are:

- Aerial applications show a higher potential for drift than ground applications when spraying similar droplet sizes.

- Ultra low volume sprays are usually applied as smaller particles than low volume sprays and are generally more susceptible to drift.

- Particle size definitely affects the drift potential of sprays and solids as well. Smaller particles are highly subject to drift at sizes below 50 μ.

- Stable atmospheric conditions produce fewer total quantities of particle drift than unstable conditions.

Though these conclusions are basic and seemingly self-evident, they provide good guidelines to show some of the factors which must be considered if drift is to be minimized.

Akesson and Yates have found much more detailed information than that presented above, but to include all of their findings in this report would require a great deal of space. The results of their work in determining spray drift from aircraft is best summarized by presentation in a table they have constructed to show the estimated amounts of drift that accompany aerial applications. Table A-1[2] represents the knowledge and experience they have on the subject of drift in aerial spray applications, and gives a good overview of the problem dealt with in this study.

G. W. Ware et al., have also conducted a number of drift tests at the University of Arizona, Tuscon. They examined the effects of several variables, including formulation, thickeners, temperature, time of application, and gallons of spray per acre, that affected the percent of pesticide deposited on-target from aerial spray applications. A summary of a number of tests conducted over a period of time is given in Table A-2.[3]

Table A-2 shows that over a long period involving a number of variables and different conditions, the average on-target deposit of aerially applied pesticides was about 50%. Dust had the lowest deposit in the target area by far--only 14%. The spray deposits varied from 28 to 73%, depending on the variables involved. This table is a good indication that aerial spraying is subject to wide variations in drift losses, and, on the average, pesticides sprayed from aircraft have only a 50% chance of reaching their intended target.

Table A-1. AIRCRAFT SPRAY DROP SIZE RANGE, USE AND APPROXIMATE RECOVERIES

Spray description atomizer	Atomizer example[a]	Drop size range (microns µm VMD)[b]	Percent estimated deposit in 1,000 ft[c]	General use
Coarse aerosols Cone and fan nozzles, and rotary atomizers	80,005 down D2-13 down 200-300 lb/in^2	< 125	< 25	For aerosol applications, vector control and forest insects. Agricultural pathogens, low volume rates, primarily adulticiding use.
Fine sprays Cone and fan nozzles, and rotary atomizers	80,005 down D6-45 down 50-100 lb/in^2	100-300	40-80	Primarily for forest pesticide chemicals and large area vector control with low dosages of low toxicity and rapid degradation chemicals. Also for agricultural insect pathogens.
Medium sprays Cone and fan nozzles, and rotary atomizers	D6-46 down 30-50 lb/in^2	300-400	70-90	Commonly used spray drop size for all low toxicity agricultural chemicals where good coverage is necessary.
Coarse sprays Cone and fan nozzles Spray additives	D6-46 back 30-50 lb/in^2	400-600 with additives up to 2,000	85-98	Recommended for toxic pesticides of restricted classification where thorough plant coverage is not essential.
Minimum drift sprays Jet nozzles Spray additives	D4 to D8 down at less than 60 mph. Back at over 60 mph. 30-50 lb/in^2	800-1,000 with additives up to 5,000	95-98	Recommended for all toxic, restricted class herbicides such as phenoxy-acids and others within limitations of growing season and nearness to susceptible crops.
Maximum drift control Low turbulence nozzles	Microfoil® Less than 60 mph airstream	800-1,000	99.+	Actual drift tests show one-fourth the drift residue levels at 500 ft downwind from the Microfoil® compared with the D4 to D8 jets used with restricted nonvolatile herbicides, phenoxy-acids and others in the area of susceptible crops, but subject to limitations of growing season and crop.

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[a] Numbers refer to Spraying Systems Company, nozzles, down or back refer to position on aircraft boom.

[b] Drop size as determined with water base sprays, oils would give smaller drops.

[c] Deposit estimated in 1,000 ft downwind. Weather conditions: wind velocity 3-5 mph, neutral temperature, gradient. Material released under 10 ft height.

Source: Akesson, N. B., and W. E. Yates, "Physical Parameters Relating to Pesticide Application," p. 29, paper supplied by N. B. Akesson (1974).

Table A-2. PERCENTAGE ON-TARGET DEPOSIT OF AERIALLY APPLIED INSECTICIDES

Insecticide (AI/acre)	Time of application	Gallon spray/acre	Spray thickener	Temperature (°F)	Relative humidity (%)	Wind (mph)	Sample height (in.)	Actual % deposited	Corrected % deposited
Toxaphene 4.0	6:10 PM	15% dust	-	61	55	3-4	-	14.0	14.0
Toxaphene 4.0	6:10 PM	5.7	-	61	55	3-4	-	47.7	47.7
Methorychlor 1.75	9:20 AM	8	Yes[a]	93	-	4.9	18	34.4	39.3
Methoxychlor 1.75	9:20 AM	8	-	93	-	4.9	18	38.3	43.8
Methoxychlor 1.75	8:15 AM	7	-	36	-	1.4-2.6	10	69.5	96.5
Methoxychlor 1.75	8:15 AM	7	Yes[a]	36	-	1.4-2.6	10	73.0	107.0
Methoxychlor 1.72	5:54 AM	7	-	60-70	-	1-2.5	18	28.0	35.4
Methoxychlor 1.72	4:00 PM	7	-	95-100	-	2-3.5	18	44.0	53.7
Methoxychlor 2.0	8:20 PM	8	-	83-86	-	< 1.0	ground	33.7	35.4
Methoxychlor 2.0	8:20 PM	8	-	83-86	-	< 1.0	24	69.2	72.8
Methoxychlor 2.0	6:15 PM	5	Yes[b]	90-94	35	4.5-5.5	12	40.4	40.4
Methoxychlor 2.0	7:00 PM	5	-	87-93	45	1.8-2.0	12	38.4	39.7
Methoxychlor 2.0	5:30 PM	5	-	98-103	44	2.9-3.7	12	72.0	72.0
Methoxychlor 2.0	4:50 PM	5	Yes[c]	100-105	19	5-5.6	12	61.3	61.3
Methoxychlor 2.0	5:50 PM	5	Yes[d]	99-103	25	2-3	12	28.0	28.0
Methoxychlor 2.0	3:00 PM	5	-	103-105	28	1.8-2.7	12	32.8	44.2
Methoxychlor 2.0	3:00 PM	5	-	103-105	28	1.8-2.7	12	35.8	36.0
							Average	46.7	53.3

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a/ Spray thickener employed was carboxymethyl-cellulose.
b/ Spray thickener employed was Decagin 0.8% (w/w).
c/ Spray thickener employed was molasses (24% V/V).
d/ Spray thickener employed was Cab-O-Sil (3.5% w/w).

AERIAL APPLICATION - TIME OF APPLICATION AND DRIFT

The objective of this study, conducted by Ware et al. (1972),4/ was to determine effects on target deposit and drift when pesticides were applied at a rate of three times daily under different meteorological conditions. Methoxychlor with a fluorescent tracer was applied aerially at a rate of 0.46 lb/acre from a height of 5 to 6 ft at 90 mph using 28 Delavan D-2 floodtip nozzles. Applications were made at 6 a.m. (I), 3 p.m. (II), and 6:50 p.m. (III); all under a 2 to 3°F temperature inversion. The dispersion of the pesticide was determined by analysis of horizontal vertical collection cards placed 18 in. above ground level in both the target area and at distances of 82, 165, 330, 660, and 1,320 ft downwind, and by analysis of 10, 1-ft^2, alfalfa samples. Pertinent meteorological data and target deposit and drift of the pesticide for the three applications are shown in Table A-3.

On the basis of these tests it was concluded that early morning application resulted in greater insecticide deposit in the target area. However, downwind drift deposit beyond 660 ft was increased. The relatively greater deposit of the early morning application is probably due to a mild temperature inversion in conjunction with lower temperature and higher relative humidity that reduced evaporation from spray droplets.

AERIAL APPLICATION - LOW VOLUME VERSUS ULTRA LOW VOLUME SPRAYS

Brazzel et al. (1968)5/ conducted a study in which several pesticides were applied aerially using two methods, ULV and diluted EC, to determine the effect of formulation on the amount of drift. ULV formulations (which are typically applied in amounts of 1/2 pt to 1/2 gal. active ingredient per acre) were applied with an EC boom (D-8 orifices and No. 45 Core) at rates of 1 to 1/2 gal. liquid per acre. EC formulations (which are water diluted and typically applied in volumes of 1 to 10 gal/acre) were applied with the same boom, but with 80015 nozzles and a Micronair® atomizer, at rates of 1.5 gal/acre. EC and ULV sprays were each applied at 5 and 20 ft flight heights under conditions in which the wind speed ranged from 2 to 14 mph. The deposit efficiency of the pesticides was determined in a 100 ft target area.

The results of this field study were as follows:

1. Application at a 20 ft flight height resulted in greater drift and less deposit in the target area for both formulations.

2. Overall environmental contamination with ULV was less than with EC applications.

Table A-3. TIME OF APPLICATION VERSUS TARGET DEPOSIT AND DRIFT

Time of application	Relative humidity 0-ft	Relative humidity 8-ft	Wind (at 8 ft) speed	Wind (at 8 ft) direction	Temperature 8-ft	Temperature 32-ft	Target deposit	Drift
6:00 a.m.	69%	66%	1.5 mph	S	79°F	82°F	75.4%	24.6%
3:00 p.m.	28%	34%	3.6 mph	W	101°F	103°F	63.3%	36.7%
6:50 p.m.	28%	42%	3.2 mph	NW	99°F	101°F	54.7%	45.3%

3. The greater efficiency of ULV applications appeared to be due to less evaporation from the droplets. ULV formulations require dispersal as very small droplets to achieve adequate coverage and to avoid phytotoxicity. The droplets dispersed in the 100 to 150 μ range remained heavy enough to fall to the ground in the target area. On the other hand, EC droplets, although initially large, rapidly lost size and weight due to evaporation of the water and became more subject to drift.

4. Tests showed that: "as droplet size increased, percentage recovery in the target area increased, but droplet count decreased. Droplet counts were usually higher with EC, but percentage recovery was lower than for ULV. These results indicate a considerable increase in efficiency of application to a specific target area with an increase in droplet sizes from 100 to 150 μ. However, this increase is accompanied by a decrease in coverage in the target area. Also, these results indicate a reduction in drift, since more of the pesticide reached the target area."

5. A summary of the data obtained for the 12 field tests is given in the following table (Table A-4).

AERIAL APPLICATION - LOW VOLUME VERSUS ULTRA LOW VOLUME SPRAYS

This field test was conducted by Adair et al. (1971)[6] to determine the effect of formulation on drift under similar application conditions. Methyl parathion was applied in two formulations. A 4 lb/gal emulsifiable concentrate (EC) formulation, applied both as an undiluted ULV spray and a water-diluted (low volume) spray (2 gal/acre). Both formulations were applied aerially at 80 mph and a height of 5 ft. ULV applications were made with 12 No. 80015 nozzles at the rate of 1 lb/acre, and with 24 No. 80015 nozzles at the rate of 2 lb/acre. LV applications were made by 12 D-8 tip and No. 45 core disc-type cone spray nozzles at the rate of 1 lb/acre.

Ground impaction sheets, oil-sensitive cards, and Casella® cascade impactors (placed 5 ft above ground level) were used to determine the amount of methyl parathion deposited in the target area, at distances of 10 and 20 ft upwind, and at distances up to 1/2 mile downwind. The ground impaction sheets and oil-sensitive cards were collected 20 min after pesticide application; cascade impactors at 100, 330, 660, 1,320, and 2,640 ft downwind were operated 2, 5, 7, 10, and 15 min, respectively, after application and were removed 30 min after sampling ceased.

The results of these tests were as follows:

1. Analysis of oil-sensitive cards indicated that the larger drops fell to the ground in the flight path and that drops impacting away from target area decrease in size as distance from the target area increases.

Table A-4. PERCENTAGE PESTICIDE RECOVERY IN A 100-FT TARGET AREA

Formulation	Application height (ft)	Application system	Wind (mph)	Target recovery (%)
ULV	20	ULV boom	2	44.33
ULV	5		2	47.90
EC	20	EC boom	3	11.51
EC	5		4	14.97
ULV	20	ULV boom	10	4.48
ULV	5		11	10.26
EC	20	EC boom	12	1.27
EC	5		14	5.91
ULV	20	ULV boom	10	16.00
ULV	5		11	28.67
ULV	20	Micronair®	6	1.04
ULV	5	22.5°	8	17.96

The analysis also showed that 70 μ sized droplets could drift up to 1/2 mile downwind.

2. Airborne drift at a 5-ft height, as determined using the cascade impactors, showed that drift was greater from ULV applications than from LV applications. In addition, the amount of airborne drift at the 5-ft height quickly stabilized in LV applications while airborne ULV drift was high at 100-ft downwind, gradually decreasing as downwind distance increased.

3. LV sprays were deposited in the narrow target area with more efficiency, but since relatively less was deposited downwind, a large quantity must be quickly airborne. This may be due to water evaporating from the initial droplet leaving a very small droplet which remains airborne.

4. Table A-5 shows the average percent recovery of methyl parathion on the ground impaction sheets, both in the target area and at distances of up to 1/2 mile. These data show that ground downwind deposit of methyl parathion was greater from ULV applications than from LV applications.

5. The previous table shows that a 40-ft swath for LV and 80-ft swath for ULV gave similar deposition in the target area, but more pesticide impacted on the ground downwind using the ULV spray.

AERIAL APPLICATION - DILUTE VERSUS LOW VOLUME SPRAYS

Low volume application of pesticides requires atomization into fine droplets which results in an increased drift hazard. A field study was performed by R. J. Argauer et al.,7/ to compare deposits of malathion and azinphosmethyl when aerially applied as LV (low volume) and water-diluted emulsifiable concentrates. Tests were performed under adverse climatological conditions to determine maximum possible drift.

Pesticide applications were made aerially at 100 mph at heights of 8 and 30 ft. LV applications of malathion and azinphosmethyl were made using the undiluted technical formulations. Water was added to the technical formulations when applying the dilute sprays. Azinphosmethyl was applied at a rate of 0.5 lb active ingredient per acre and malathion at 2.0 lb active ingredient per acre, active ingredient constant regardless of formulation. LV applications were made using a No. 8002 flat spray nozzle directed 45 degrees forward and down into the airstream; water-diluted spray applications were made with a No. D10-45 hollow-cone nozzle directed straight down into the airstream. Mass median diameter of the droplets in each case was approximately 220 μ.

Table A-5. PERCENT RECOVERY OF METHYL PARATHION ON GROUND IMPACTION SHEETS

Formulation and pound active ingredient per acre	Swath width	Average % recovery								
		Target area	Downwind							
			40	60	80	100	330	660	1320	Total	% Drift
ULV 1.0 lb/acre	40 ft	15.7	9.6	6.6	6.9	3.9	1.10	.10	.03	43.9	56.1
ULV 2.0 lb/acre	40 ft	16.2	14.5	4.8	2.5	2.3	.60	.10	.05	41.0	59.0
ULV 1.0 lb/acre	80 ft	31.7	--	9.6	5.0	4.6	1.20	.20	.10	52.4	47.6
LV 1.0 lb/acre	40 ft	32.8	6.0	3.5	1.9	0.7	.60	.04	.02	45.5	54.5

Relative spray deposits were determined by: (a) analysis of glass-fiber filter discs attached to aluminum plates placed perpendicular to the flight line and parallel to the wind direction; and (b) laboratory bioassay of open Petri dishes placed near each collection plate. The relative amounts of airborne azinphosmethyl 6 ft above ground at 200 and 2,000 ft downwind of the application line were determined using two Staplex® high volume air samplers. Filter discs from the azinphosmethyl test were analyzed by a fluorometric method; filter discs collected after the malathion test were analyzed by gas chromatography. Bioassays of the Petri dishes were performed by placing 1 to 7-day-old adult *Drosophila melanogaster* in each dish; dishes were examined and records of fly mortality were kept.

Pesticide amounts recovered were estimated by adding the amount recovered in the swath path to the amount recovered immediately downwind. Estimated recoveries for azinphosmethyl and malathion applications at two flight heights are shown in Table A-6.

Recovery of the diluted applications ranged from 46 to 96% of total pesticide applied; average recovery for the three tests was 71%. Recovery from the undiluted low volume tests ranged from 18 to 62%, with the average recovery for the four tests 37.5%. In addition, it was determined that more pesticide was recovered when applied from the 30 ft flight height than when applied from the 8 ft flight height. It was postulated that the lower pesticide recovery from the lower application height may be due to severe turbulence caused by the aircraft slipstream reflected by a swirling pesticide deposit pattern in the swath area. At the higher flight pattern, however, drift to adjacent areas was more pronounced due to an increased influence from crosswinds.

AERIAL APPLICATION AND MIST-BLOWER APPLICATION COMPARED

Ware et al.,[8/] conducted a study exploring pesticide drift differences between aerial and tractor-drawn mist blower applications. Aerial and mist-blower (ground) applications to alfalfa fields were made simultaneously in late afternoon. Pertinent meteorological and application data are shown in Table A-7.

Downwind drift contamination was determined by three techniques: (a) analyses of alfalfa samples collected along two drift lines and at 165, 330, 660, 1,320, and 2,640 ft downwind; (b) air scrubbers (operated 66 min for mist applications and 28 min for aerial applications) stationed at four positions, 165 and 330 ft downwind; and (c) glass plates (10 x 25 cm) placed 10 in. above ground at target site and at 165, 330, 660, and 1,320 ft downwind along both drift lines.

Table A-6. ESTIMATED PERCENTAGE SPRAY RECOVERY IN THE SWATH ZONE TO 0.375 MILES DOWNWIND

	Undiluted, technical formulation		Diluted, aqueous formulation	
Pesticide	8 ft application height	30 ft application height	8 ft application height	30 ft application height
Azinphosmethyl 0.5 lb/acre	18%	62%	46%	--
Malathion 2.0 lb/acre	31%	39%	71%	96%

Table A-7. APPLICATION DATA: AFTERNOON APPLICATION OF METHOXYCHLOR FROM BOTH A MIST BLOWER AND AIRCRAFT

Application method	Time of application	Wind direction and velocity	Temperature	Application speed	Nozzle pressure and size
Mist blower	4:30 p.m.	W-SW 3.0-5.0 mph	8 ft: 80°F 33 ft: 75°F	4 mph	25 psi Remite® slot-type
Aerial	4:30 p.m.	W-SW 3.0-5.0 mph	8 ft: 80°F 33 ft: 75°F	80 mph	50 psi D-8 tip, No. 45 core

All three techniques showed that downwind drift was greater from mist-blower ground application than from aerial applications. "Alfalfa 1/2 mile downwind from the mist blower bore 0.27 ppm [pesticide], with only 0.14 ppm from aerial application." Greater drift from mist-blower applications was also confirmed by analyses of data from the glass plates and air scrubbers.

Droplet size was determined by using microscope slides (1 x 3 in.) placed 10 in. above ground in the target area and at 1,320 ft downwind; slides were collected 30 min after completion of application and droplet spread-diameter determined. Results indicated the mist blower had an average droplet size of 100 μ in the target area and 18 μ at 1,320 ft downwind. Average droplet size in the target area and 1,320 ft downwind was 140 and 34 μ, respectively, for the aerial application.

Thus, each drift measurement technique indicated greater downwind drift to 1/2 mile occurred during mist-blower application than during aerial application. Ware et al. postulated that this was due to mist-blower applications having a smaller droplet size and higher droplet initial velocity (often in excess of 90 mph) both of which contribute to a greater drift hazard.

AERIAL APPLICATION AND GROUND APPLICATION COMPARED

Ware et al.,[9] conducted a field study in 1967 to compare: (a) insecticidal drift when applied simultaneously by ground rig and by "standard" aircraft sprayer; and (b) to determine the drift from morning versus late afternoon applications.

Ground applications were made by a high clearance ground sprayer (High Boy, Model 300 FSP, Hahn, Inc.) driven at 3 to 4 mph with 40-psi boom pressure. Methoxychlor emulsion was applied in the evening test at a rate of 70 gal. spray per 10 acres (1.5 lb active ingredient per acre) and in the morning test at a rate of 80 gal. spray per 10 acres (1.8 lb active ingredient per acre).

Aerial applications were made using a Stearman biplane flown at 80 mph (flight height not available) with a 42-ft swath, and 36 No. 8 nozzles at 30 psi. Methoxychlor was applied at the rate of 70 gal. spray per 10 acres (2.0 lb active ingredient per acre) in both the morning and evening tests.

Meteorological conditions during the field tests were as follows: (a) evening--wind from the northwest, 1 mph; temperature inversion of 3 degrees ranging from 83°F at 8 ft to 86°F at 32 ft; relative humidity not recorded; and (b) morning--wind from the southeast, 1 to 2 mph; temperature lag of 0 to 2°F within 80 to 85°F; relative humidity varying from 72% at 7:00 a.m. to 55% at 9:00.

Relative drift during applications was determined by three Anderson Air Samplers, four Casella® cascade impactors and one air scrubber (morning and evening tests) in addition to two M-S-A Monitaire® samplers attached to the shirt pocket of the airplane flagman and Hi-Boy operator (evening tests only). Naturally impinging drift was measured by glass plates placed at ground level and 24 in. above ground in the target area and at 82, 165, 330, 660, 1,320, 1,990, and 2,640 ft downwind for the evening tests and in target area and at 82, 165, 330, and 660 ft downwind for the morning tests. All analyses were by gas chromatography.

Conclusions drawn from this field test were as follows:

1. At all distances, drift from aerial application was greater than from ground application (e.g., aerial application drift at 1,320 ft was five times greater than ground application drift for the evening test; aerial application drift at 660 ft was 4.2 times greater than from ground application in the morning test application).

2. Impinging drift at ground level was the same quantity as that at 24 in. In addition, drift deposits at these two levels were similar for morning and evening aerial applications. However, deposit at 660 ft for ground application in the morning was 2.6 times greater than deposit for the evening application.

3. The M-S-A Monitaire® samplers determined methoxychlor exposure was at a rate of 0.035 $\mu g/ft^3$ for the airplane flagman and 0.016 $\mu g/ft^3$ for the Hi-Boy operator; however, the ground equipment operator received a greater pesticide exposure due to a greater exposure time (58 min versus 19 min).

4. Finally, it was determined that, at 165 ft downwind, more small droplets were airborne during aerial application than during ground application.

GROUND APPLICATION - EFFECTS OF AN ADDITIVE, NOZZLE PRESSURE, AND EVAPORATION ON DRIFT

Paired field studies were performed by Goering and Butler (1973)[10] to evaluate ground rig sprayers. To assure application under identical conditions, a dual sprayer, equipped with No. 8802 flat fan nozzles spaced 20 in. apart was mounted on the tractor to produce a swath width of 160 in. The tests were conducted using a dual application. Each mix tank contained a different fluorescent dye tracer. Downwind drift was monitored by clear mylar collection sheets. Nozzles were calibrated with water prior to drift experiments; measured flow rates were within 4% of the expected rate.

The following effects were evaluated: (a) the effect of a spray thickener additive on drift; (b) effect of nozzle pressure on drift; and (c) effect of 2,4-D amine on evaporation and drift.

The tests consisted of conducting paired studies: (a) with and without a spray additive (E-102) (Tests I, II, III, IV, and IX); (b) with and without 2,4-D amine (Test V); and (c) with different nozzle pressures (Tests VI, VII, and VIII). All test applications except one (V) contained 1.0% 2,4-D amine; V-a contained 0.0% 2,4-D amine. Results are shown in Table A-8.

Spray recovery was 70% or more of the total applied in all experiments except one. Conclusions from these studies were:

1. "The E-102 spray thickener reduced both the amount of drift deposits and the amount of spray loss by increasing deposits within the swath."

2. "Lowering the nozzle height decreased the drift deposits."

3. "Lowering the nozzle pressure decreased the spray loss."

4. "Low temperatures and high relative humidity were associated with decreased drift and decreased spray loss."

5. "Increased air turbulence produced greater spray loss, but less downwind drift deposits."

6. "Increased horizontal wind speed produced greater spray loss, but produced either greater or smaller drift deposits, depending upon other meteorological factors."

GROUND APPLICATION - SPRAY DRIFT IN TREATING ORCHARDS

Pesticide spray treatment of orchards is normally done by sprayers mounted on ground equipment. Thus, a considerable amount of the spray must be directed upwards and as such, is subject to drift out of the orchard. Consequently, to avoid drastically harming nearby crops or wildlife the fruit grower chooses relatively "safe" pesticides from which drift hazard is minimal. Byass and Charlton (1964)[11] conducted a study to measure the percentage of the applied pesticide impacting on the downwind trees.

Table A-8. SUMMARY OF RESULTS FROM PAIRED FIELD STUDIES OF DRIFT

Test No.		Temp (°C)	Relative humidity (%)	E-102 (%)	Cumulative recovery (%)[a]
I	a Control	14.6	51.0	0.0	96.9
	b E-102			0.125	104.9
II	a Control	11.9	50.0	0.0	83.8
	b E-102			0.1	100.0
III	a Control	17.9	23.0	0.0	101.4
	b E-102			0.0625	113.8
IV	a Control	14.7	48.0	0.0	70.9
	b E-102			0.0625	90.0
V	a Control	13.9	47.0	0.0	72.0
	b 2,4-D amine			0.0	90.0
VI	a 40 psi	22.3	29.0	0.0	52.2
	b 25 psi			0.0	72.4
VII	a 40 psi	27.8	38.0	0.0	78.5
	b 25 psi			0.0	82.0
VIII	a 40 psi	30.1	38.0	0.0	91.9
	b 25 psi			0.0	82.1
IX	a Control	31.7	42.0	0.0	108.2
	b E-102			0.1	130.1

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[a] Cumulative recovery includes deposits in the target area and to 1,024 ft downwind. These figures may exceed actual recovery due to overcorrection for dye degradation and correction to zero wind direction; uncorrected figures ranged from 48.8% to 100.3%.

Narrow, folded celluloid slides with a high collection efficiency (approximately 80% for 50 μ droplets at 10 ft/sec) and a size comparable to twigs were used to estimate the amount of pesticide settling on twigs. In addition, spray deposits on apple leaves were measured by dye colorimetry. All dye applications were made in plain water solutions. Pertinent meteorological data were recorded for all applications. Data from nine application tests measuring percentage of deposit on the trees attributable to drifting spray are shown in Table A-9.

It was concluded that in moderate winds: (a) "up to 40% of the final deposit in an orchard sprayed at high volume by air-carried spray may be due to spray settling beyond the sprayed row;" (b) "settling spray will be at a level of about 10% of the dose applied to the sprayed tree at about 100 ft downwind;" if winds are light, settling amount is unpredictable; and if winds are strong, 10% may settle 200 ft downwind.

Table A-9. SPRAYING CONDITIONS AND PROPORTION OF TOTAL LEAF DEPOSIT FROM DIRECT APPLICATION AND DRIFT

Machine setting (gal/acre)	Machine speed (ft/sec)	Temperature (°F)	Relative humidity (%)	% Deposit				
				Target rows	Downwind rows 1st	2nd	3rd	Beyond 3rd row
8-1/3	4.8	53	55	89	7	T*	T	4
8-1/3	5.9	66	60	75	13	7	T	5
10	6.0	56	50	83	13	3	T	1
50	10.3	55	50	75	18	4	T	3
50	6.7	67	60	68	20	7	T	5
125	7.5	57	50	95	T	T	T	-
200	8.9	55	50	62	19	9	5	5
200	7.6	69	60	63	19	9	T	9
250	8.5	58	45	77	10	6	5	2

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* Trace amount.

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APPENDIX B

FIELD STUDIES ON PESTICIDE RUNOFF AFTER APPLICATION

As a result of the review of the literature, a number of field studies on the concentrations of pesticides in runoff water from croplands and on the percentages of pesticides lost in runoff and soil erosion were obtained. A brief discussion and the important findings of each study are given below in the two separate categories given above. The references used to obtain these studies appear at the conclusion of this appendix.

CONCENTRATIONS OF PESTICIDES IN RUNOFF

For the data obtained in this section, we used nine field studies conducted to determine the concentration (ppm) of pesticides in the runoff water from field crops and watersheds. Each of these studies is briefly described below and then the results of all the studies are summarized.

1. Willis[1/] studied the concentration of endrin in surface runoff from a sugarcane field on Mhoon clay loam soil in Baton Rouge, Louisiana. The concentrations found were 1.06 and 0.46 ppb when rain followed the application within 24 and 72 hr, respectively.

2. Kearney[1/] studied the concentration of 2,4-D, picloram, 2,4,5-T, and dicamba in watershed runoff in North Carolina. The results of the 3-year study were: (a) no dicamba or picloram was detected, and the highest concentration of 2,4-D was 28 ppb, in 1967; (b) in 1968 the concentrations measured were 1,224, 583, and 229 ppb for 2,4-D, 2,4,5-T and picloram, respectively; and (c) the first storm gave the highest concentrations detected in runoff for 2,4-D, 2,4,5-T, and picloram, and those concentrations were 1,882, 681, and 4,187 ppb, respectively.

3. Axe et al.[2/] studied the concentrations of atrazine, propazine, and trifluralin in runoff water from Pullman silty clay loam soil in West, Texas. They found the highest concentrations to be 40, 50 and 40 ppb for trifluralin, propazine, and atrazine, respectively.

4. Sheets et al.[3/] studied the concentration of picloram, 2,4-D, and 2,4,5-T in runoff water from mixed grass sward-covered fields of loam (sandy to clay) soil in Waynesville, North Carolina. During the 4-year study, they found that the concentrations of 2,4-D in surface runoff from the first rain after application were 1,200, 1,900 and 2,500 ppb, during 1968, 1969, and 1970, respectively. The concentrations for the other two chemicals were less than those of 2,4-D. (They were not given.)

5. Caro et al.[4] studied the concentration of carbofuran in runoff from silt loam soil planted in maize in Coshocton, Ohio. The results of that study showed that concentrations in runoff were greatest within the first month after application. For a broadcast application of carbofuran, the runoff concentrations ranged from 1,394 ppb, 25 days after application, to 5 ppb, 239 days after application. For a band application of carbofuran, runoff concentrations ranged from 13,674 ppb, 28 days after application, to 3 ppb, 119 days after application. In both cases, the highest concentration was 677 ppb after 1 month from the time of application.

6. Caro et al.[5] studied the concentration of dieldrin in runoff water from a Muskingham silt loam soil watershed in Coshocton, Ohio. The highest dieldrin concentration in the water was 20 ppb soon after application, and did not exceed 4 ppb in two of the 3 years in which the study was conducted.

7. Ritter et al.[6] studied the concentrations of atrazine, propachlor, and diazinon in runoff from four watersheds of silt loam soil in Castana, Iowa. Atrazine ranged from 4,910 to 1,170 ppb in the 3-year study. Propachlor was undetected in two of the 3 years, and ranged from 780 to 200 ppb in the other year. Diazinon was undetected in all but one water sample, whose concentration was not given.

8. Hall et al.[7] studied atrazine concentrations in runoff water from 14 plots of Hagerstown silty clay loam soil planted in corn during 1967 and 1968. Amounts of atrazine applied at the recommended rate (2 lb/acre) gave a concentration of 1,390 ppb in 1967 in the first storm. Each successive runoff showed lesser concentrations, all below 200 ppb 1 month after application, or later.

9. White et al.[8] studied atrazine concentrations in runoff from watersheds of Cecil sandy loam soil at Watkinsville, Georgia, in 1965. Atrazine applied 1 hr before a simulated rainstorm gave concentrations of 1,670 to 1,100 ppb in runoff, while application 96 hr before the storm gave concentrations of 700 to 540 ppb in the runoff. Different intensity storms showed that the average concentrations of atrazine in water for runoff values of 0.07, 0.61, and 1.54 in. were 7,940, 2,540 and 1,390 ppb, respectively, when applied 1 hr before the rain; and 3,660, 1,130, and 620 ppb, respectively, when applied 96 hr before the rain.

PERCENTAGES OF PESTICIDES LOST IN RUNOFF AND EROSION

Studies have been conducted on carbofuran, dieldrin, picloram, diazinon, propachlor, atrazine, and 2,4-D, to determine the amount of pesticide lost in both the runoff and sediment as a percentage of the amount applied. These studies are given below by pesticide, and the results of these studies are subsequently discussed.

Carbofuran

In a study conducted by Caro et al. (1973)[4] two watersheds planted with maize were treated with carbofuran in 1971 and 1972 to determine the runoff losses of the pesticide. Watershed No. 113 was silt loam soil with an average slope of 9.6%. In 1971, No. 113 received a broadcast application (disked into a 3 in. depth) of 4.83 lb/acre active ingredient, and No. 118 received an in-furrow treatment (band application) of 3.71 lb/acre active ingredient. In 1972, No. 113 received an in-furrow application of 2.77 lb/acre active ingredient while No. 118 was not treated.

The important results of this study showed that:

1. The losses of carbofuran in runoff water in 1971 occurred almost entirely within the first 2 days after application due to two heavy rains in that period. These rains caused over 95% of the year's total losses in both plots. The second rain produced higher concentrations than the first from both plots, indicating the applied granules had dissolved by the second day.

2. Losses due to runoff were less in the band application than in the broadcast application for a given volume of runoff.

3. The total annual runoff losses of carbofuran, both in water and soil, were less than 2% of that applied, as shown below:

Watershed No.	Year	Kiloliters of runoff	Amount applied (lb/acre)	Type application	Carbofuran lost (%)
113	1971	44.7	4.83	Broadcast	0.9
118	1971	53.3	3.71	Band	0.5
113	1972	242.7	2.77	Band	1.9

Dieldrin

A study was conducted in Coshocton, Ohio, from 1966 to 1969 by Caro et al. (1971)[5] to determine the amount of dieldrin lost due to runoff and erosion. Two watersheds of Muskingum silt loam were disked, fertilized, and plowed 1 month before dieldrin was applied, and the application was made immediately before maize was planted. In 1966, dieldrin was applied to one plot as a uniform spray of aqueous solution from a 20 ft truck boom at a rate of 5 lb/acre, and was immediately disked into the soil to a depth of 3 in. In 1968, the other plot was treated the same way, except that the soil was cultipacked deliberately to increase the likelihood of runoff.

The 1966 plot had only two small runoff events in 1966 so no data were obtained on runoff soon after application. The 1968 plot received a rain 13 days after application, and half of the total loss of dieldrin from this plot occurred at this time. The total loss of dieldrin due to runoff and erosion was measured for 26 months on the 1966 plot, and for 8 months on the 1968 plots.

The results of this study were:

1. Dieldrin was lost from the soil mainly through volatilization and soil erosion.

2. No measurable soil erosion occurred in the 1966 plot. In contrast, six of the 14 runoff events in 1968 resulted in soil erosion from the plot. Dieldrin concentrations in the soil lost were about three orders of magnitude higher than in the associated runoff water, and 2.2% of the dieldrin applied to the 1968 plot was lost due to soil erosion.

3. Dieldrin losses in the runoff water were 0.007% of the amount applied in the 1966 plot, measured over a 26-month period, and 0.07% in the 1968 plot, measured over an 8-month period.

4. Losses of the pesticide due to soil erosion were about 30 times greater than losses due to the associated water runoff.

5. The largest losses occurred within 2 months of application.

6. No relationships were found between concentrations of dieldrin lost and volume of runoff water, maximum flow rate, or duration of runoff. No continuous decrease of concentration occurred with time.

Picloram

Picloram was applied to 96 separate experimental plots in a study conducted by Baur et al. (1972)[9/] in Carlos, Texas, in 1969 and 1970 to determine the concentrations of the pesticide in runoff water. Treatments consisted of 1.12 kg/ha of picloram sprayed at the rate of 93.5 liters/ha with a tractor-mounted sprayer. The runoff water was sampled over a 2-year period, and the plots were sprayed each year at various intervals (each plot received only one spray treatment annually).

The results of this study showed that samples of runoff water taken adjacent to the plots had a high value of 89.7 ppb (parts per billion) picloram 2 days after application and declined to less than 10 ppb by 10 to 12 weeks after application. Water sampled 1.2 km from the plots contained less than 1 ppb of picloram, 8 days after application. Eight months after treatment, occasional levels of less than 1 ppb were detected 1.6 km from the plots. In addition, most of the picloram was removed by runoff within the first 16 weeks of application, and about 50% of the total pesticide loss occurred within the first 4 weeks.

Other studies were summarized in this article and are given below:

1. Scifres et al. applied picloram to soil at the rate of 0.28 kg/ha. They detected 17 ppb in runoff water the first few days after application. Less than 1 ppb level of picloram in runoff water was detected when sprinkler irrigation was conducted 20 to 30 days later.

2. Davis et al. applied picloram at the rate of 1.04 kg/ha to soil in Arizona. Seven days after the application, high levels of 370 ppb were detected in runoff water following a 6.43-cm rain. The picloram was found in trace amounts 3 months after treatment and was undetectable after 12 months.

3. Johnsen and Warskow applied picloram to Arizona soil at the rate of 1.9 kg/ha. Runoff water from the watershed over an 18-month period showed that only 0.05% of the picloram was lost due to runoff waters.

These studies show that "the concentration of picloram in runoff water is related to the rate applied, time between application and first rainfall, amount and intensity of rainfall, and size of watershed as it influences dilution."

Diazinon

A study was conducted by Ritter et al. (1974)[6/] in Castana, Iowa, for 4 years, 1967 to 1970, to determine the loss of diazinon, propachlor, and atrazine due to runoff and erosion. Four watersheds were used that consisted of silt loam soil and had slopes of 10 to 15%. In 1967, the plots were planted to surface-contour corn and two of them were ridged at the first cultivation. From 1968 to 1970 two of the plots were planted to surface-contour corn, and two were planted to ridged corn.

Diazinon was applied to the four plots at the first cultivation each year in a band application 1 to 2 in. deep at a rate of 1 lb/acre. (Atrazine and propachlor were also used in the study and are considered in the following sections.) The results obtained for diazinon in this study were:

1. No significant amounts of diazinon were found in the surface runoff and sediment when applied at recommended rates and incorporated into the soil.

2. Highest concentration if diazinon was found in runoff and sediment samples collected 4 to 10 days after application, with a maximum of 0.1% of the total pesticide applied to the watershed in the runoff and sediment from one of the surface-contoured plots due to a storm occurring 4 days after application.

3. No severe storms occurred in the 2-year study period and the reason the losses of diazinon were low was that it was incorporated into the soil and degraded rapidly.

Propachlor

Ritter et al. (1974)[6] studied propachlor also. In 1967 and 1968, propachlor was applied to both a contoured plot and ridged plot at the rate of 4 lb/acre by spraying a wettable powder formulation. In 1969 and 1970, the same procedure was followed except that the rate of application was increased to 6 lb/acre. The runoff and sediment were then examined for propachlor.

Results of the study on propachlor were:

1. No runoff occurred in 1968 and 1969 before the propachlor had degraded.

2. In 1967 no detectable amounts of propachlor were found in water or sediment runoff from samples collected 14 and 25 days after application.

3. In 1970 a storm occurred 7 days after application and 2.6% of the propachlor was lost in the runoff from the surface-contoured plot: 2.0% in the water and 0.6% in the sediment. Runoff measurements 25 and 37 days after the application showed no propachlor loss in the sediment, and a total loss of 0.5% in the runoff water during that period. (All percentages are percent of total propachlor applied.) The total propachlor lost in the first 37 days then, was 3.1% of the total applied.

No loss occurred in the ridged plot in 1970 since the pesticide degraded prior to runoff occurrence.

Atrazine

Again using the same study in Castana, Iowa, atrazine was studied in addition to propachlor and diazinon. In 1967 and 1968, atrazine was applied to both a contour-surface plot and a ridged plot at the rate of 2 lb/acre by spraying a wettable powder formulation. In 1969 and 1970, the same procedure was used except that the rate was increased to 3 lb/acre. The runoff and sediment were then examined for atrazine loss during 1969 and 1970.

The results of this study were:

1. The amount of atrazine lost in the sediment and water runoff decreased with time after application. Two months after application, the runoff from storms contained insignificant amounts of atrazine.

2. Total losses of atrazine in the runoff for 1969 and 1970 are summarized below. The percentages given are atrazine losses as a percent of the total amount applied.

	Atrazine in water		Atrazine in sediment		Atrazine loss, total	
Year	Ridged	Surface-contoured	Ridged	Surface-contoured	Ridged	Surface-contoured
1969	3.8%	6.3%	0.1%	1.9%	3.9%	8.2%
1970	2.5%	12.3%	0.2%	3.7%	2.7%	16.0%

3. The storm that occurred 7 days after application in 1970 removed 15% of the total atrazine applied to the surface-contoured plot. The ridged plot suffered a 2.2% loss during the same storm.

Another study was conducted by Hall et al. (1972)[7] on atrazine losses in runoff water and soil sediment in 1967 and 1968. The atrazine was applied preemergent to corn on 14 plots of Hagerstown silty clay loam soil (14% slope). Seven different rates of application were used, each applied to two separate plots; they were: 0, 0.6, 1.1, 2.2, 4.5, 6.7, and 9.0 kg/ha. The plots were treated only once, on 19 May 1967. Runoff and soil erosion was then sampled for atrazine losses from the plots over the next 2 years.

The results of this study were:

1. The total amounts and the percentage of atrazine lost in runoff water and soil sediment in 1967 were:

Rates applied	Amounts (g/ha)			Percent		
(kg/ha)	Water	Soil	Water and soil	Water	Soil	Water and soil
0.6	10.0	0.2	10.2	1.7	0.03	1.73
1.1	40.0	0.8	40.8	3.6	0.07	3.67
2.2	50.0	4.3	54.3	2.3	0.20	2.50
4.5	90.0	7.5	97.5	2.0	0.17	2.17
6.7	140.0	14.9	154.9	2.1	0.22	2.32
9.0	240.0	24.9	264.9	2.7	0.28	2.98
Means	95.0	8.8	103.8	2.4	0.16	2.56

Note: The recommended rate of application was 2.2 kg/ha in 1967

2. In 1968, 1 year after atrazine application, the average loss for all rates was 0.01%.

A third study was performed by White et al. (1967)[8] at Watkinsville, Georgia, in 1965, on a Cecil sandy loam soil of 6.5% slope. Atrazine was applied to the soil surface at the rate of 3 lb/acre, and simulated rainfall was used to produce runoff and erosion. Three storm sizes were produced to represent different storms occurring in the area. Storm sizes of 0.5, 1.25, and 2.50 in. of water were used, and represent a relatively common storm; a 1-year frequency storm; and a 10-year frequency storm, respectively. Losses were determined for atrazine due to storms occurring 1 hr after application and 96 hr after application.

Results of the study showed that:

1. Atrazine applied to the surface of a dry soil is lost mainly by photodecomposition and volatilization. In a laboratory study by Kearney et al. (1964) it was found that when atrazine was applied to several soils at 95°F, up to 40% was lost by the above process in a 72-hr period.

2. The effects of storm size on atrazine losses in the runoff water and soil sediment were:

		Atrazine in washoff			
		Applied 1 hr before rain		Applied 96 hr before rain	
Storm size (in.)	Rainfall duration (min)	Total loss (lb/acre)	% Lost	Total loss (lb/acre)	% Lost
0.5	12	0.13	4.3	0.06	2.0
1.25	30	0.36	12.0	0.16	5.3
2.50	60	0.50	17.0	0.22	7.3

3. The losses shown for the 0.5-in. storm and 96-hr treatment are the most representative of field conditions. This condition gives a loss of 2.0% of atrazine in the washoff.

4. The greatest losses occurred when the rain occurred immediately (1 hr) after the application.

5. Losses of 0.1 lb/acre or less would be most frequently encountered under actual field conditions.

2,4-D

Barnett et al. (1967)[10/] conducted a study of 2,4-D using Cecil soil (5% slope), and showed that losses in washoff were 13% for the butylether ester and 4% for the amine salt forms of 2,4-D. The application rate was 2.2 lb/acre, and measurements were taken following a 30-min rain of 1.25 in. This suggests that atrazine and 2,4-D are similar in their susceptibility to loss by washoff from agricultural land. (Atrazine showed a 12% loss from the same rain, 1 hr after treatment.)

REFERENCES TO APPENDIX B

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10. Barnett, A. P., E. W. Hauser, A. W. White, and J. H. Holladay, "Loss of 2,4-D. Wash-Off from Cultivated Fallow Land," *Weeds*, **15**:133-137 (1967).

APPENDIX C

PESTICIDE USAGE ON THE U.S. CORN, SORGHUM, AND APPLE CROPS (1971)

The information in this appendix was obtained from: (1) "Farmers' Use of Pesticides in 1971--Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b); (2) MRI estimates of individual pesticide usage by region; and (3) U.S. Department of Agriculture, "Agricultural Statistics, 1973," U.S. Government Printing Office, Washington, D.C. (1973).

Figure C-1 shows the USDA farm production regions (10) that are referred to throughout the appendix. Figures C-2 and C-3 show the U.S. corn and sorghum acreage planted in 1971 (by state), respectively. Figure C-4 shows the U.S. commercial apple production (in millions of pounds) by state in 1971. Statistics for Figures C-2 through C-4 were obtained from reference (3) above.

Tables C-1 through C-11 give the pesticide usage on the three crops in 1971. Tables C-1, C-5, and C-7 were obtained from references (1) above. The remainder of the tables were all developed by MRI based upon the information given in reference (1) above. These tables show the estimated usage of the individual major pesticides on each crop--corn, sorghum and apples--by region.

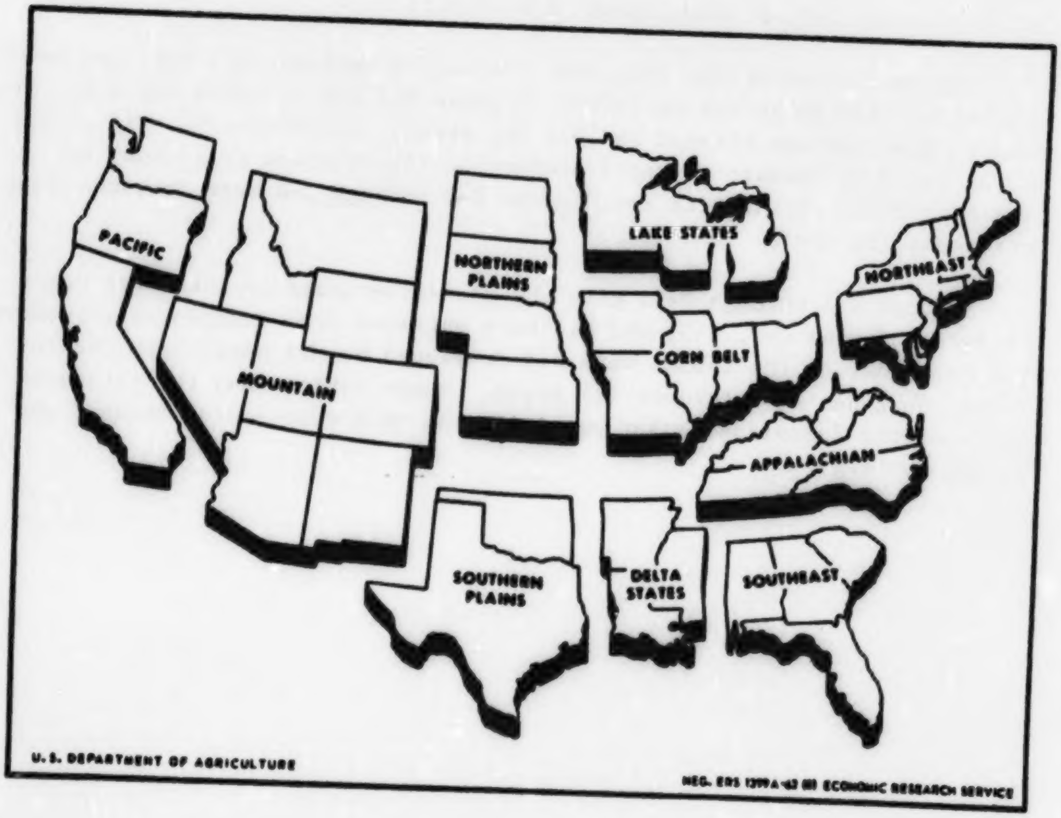
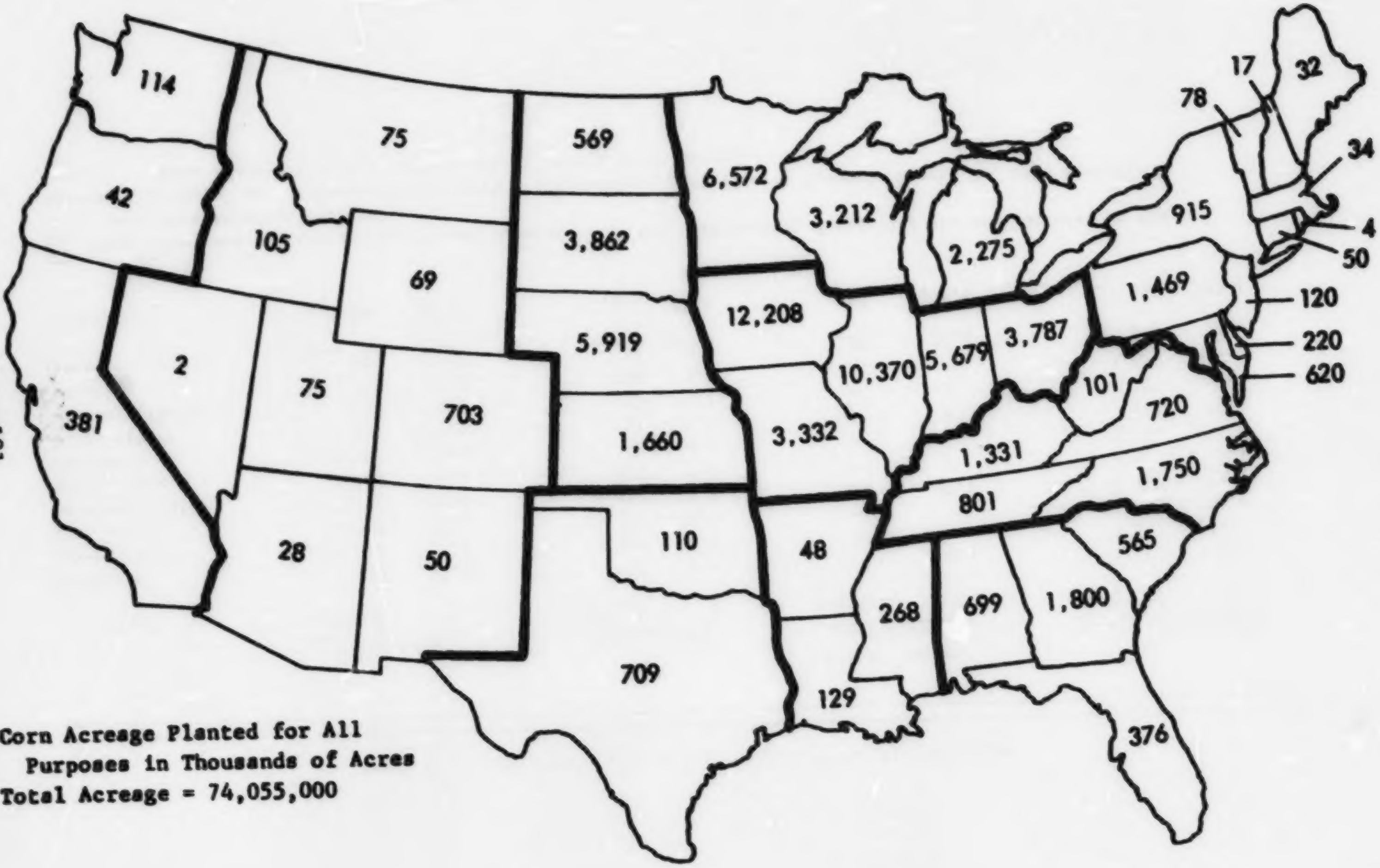

PACIFIC
MOUNTAIN
NORTHERN PLAINS
LAKE STATES
CORN BELT
NORTHEAST
APPALACHIAN
SOUTHERN PLAINS
DELTA STATES
SOUTHEAST
U. S. DEPARTMENT OF AGRICULTURE
NEG. ERS 1299A-63 (8) ECONOMIC RESEARCH SERVICE

Figure C-1. Farm production regions.


114
75
569
6,572
32
17
78
34
42
105
69
3,862
3,212
2,275
915
4
50
120
1,469
12,208
5,919
10,370
5,679
3,787
220
620
2
75
703
101
720
381
1,660
3,332
1,331
1,750
801
110
48
565
28
50
268
699
1,800
709
129
376

Corn Acreage Planted for All
Purposes in Thousands of Acres
Total Acreage = 74,055,000

Figure C-2. U.S. corn acreage (1971), by state.

Table C-1. PESTICIDE USAGE ON U.S. CORN CROP IN 1971 BY REGION

Region	Herbicides 1,000 lb	Herbicides %	Insecticides 1,000 lb	Insecticides %	Miscellaneous pesticides 1,000 lb	Miscellaneous pesticides %	Total pesticides[a] 1,000 lb	Total pesticides[a] %
Northeast	5,250	5.2	155	0.6	1	0.2	5,406	4.3
Lake States	21,358	21.1	2,749	10.8	-	-	24,107	19.0
Corn Belt	54,069	53.5	15,314	60.0	-	-	69,383	54.6
Northern Plains	10,700	10.6	5,852	22.9	386	87.1	16,938	13.3
Appalachian	6,166	6.1	375	1.5	-	-	6,541	5.1
Southeast	2,105	2.1	42	0.2	-	-	2,147	1.7
Delta States	474	0.5	37	0.1	-	-	511	0.4
Southern Plains	127	0.1	54	0.2	-	-	181	0.1
Mountain	566	0.6	928	3.6	-	-	1,494	1.2
Pacific	245	0.2	25	0.1	56	12.7	326	0.3
Total	101,060	100.0	25,531	100.0	443	100.0	127,034	100.0

---

[a] Fungicides used on corn are not listed separately in the USDA report. Fungicides are not included in the pesticide total in this table.

Source: "Farmers' Use of Pesticides in 1971 - Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

Table C-2. HERBICIDES USED ON CORN, BY REGION, 1971[a]
(1,000 lb)

Herbicide	Regions North-east	Lake States	Corn Belt	Northern Plains	Appalachian	South-east	Delta States	Southern Plains	Mountain	Pacific	Total
Atrazine	3,600	13,000	23,600	6,300	4,500	350	300	50	250	50	52,000
Propachlor	85	5,250	13,900	2,000	5	-	40	10	-	10	21,300
2,4-D	350	1,250	4,800	1,500	750	200	60	9	200	25	9,144
Alachlor	850	1,000	5,900	100	400	50	20	20	20	-	8,360
Butylate	120	160	3,800	150	195	1,250	-	-	43	100	5,818
Simazine	110	120	500	-	120	50	-	-	-	20	920
Linuron	10	30	600	100	10	5	20	5	20	4	804
Propazine	-	-	190	170	21	185	2	13	-	2	583
EPTC	10	100	50	100	-	10	-	2	10	10	292
Dicamba	3	50	150	60	-	-	-	1	10	10	284
MCPA	2	75	4	75	-	-	-	-	-	3	159
Others	110	323	575	145	165	5	32	17	13	11	1,396
Total	5,250	21,358	54,069	10,700	6,166	2,105	474	127	566	245	101,060

Source: "Farmers' Use of Pesticides in 1971 - Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

[a] Use of each individual insecticide, by region, is an MRI estimate.

Table C-3. INSECTICIDES USED ON CORN, BY REGION, 1971[a,b]
(1,000 lb)

Insecticide	Northeast	Lake States	Corn Belt	Northern Plains	Appalachian	Southeast	Delta States	Southern Plains	Mountain	Pacific	Total
	Regions										
Aldrin	-	90	7,350	235	40	20	10	1	10	3	7,759
Bux	5	810	1,370	1,360	-	-	-	30	-	-	3,575
Carbofuran	50	790	1,140	630	20	4	12	-	30	5	2,681
Phorate	2	200	1,700	400	50	1	1	5	300	2	2,661
Diazinon	5	300	800	780	20	1	-	-	80	5	1,991
Carbaryl	20	100	400	1,000	100	2	1	5	20	1	1,649
Parathion	5	50	40	900	25	2	-	5	300	2	1,329
Heptachlor	4	10	1,090	-	-	-	-	-	-	-	1,104
Chlordane	35	200	560	-	30	4	-	3	8	2	842
Disulfoton	8	30	20	120	30	-	-	2	100	2	312
Others	21	169	844	427	60	8	13	3	80	3	1,628
Total	155	2,749	15,314	5,852	375	42	37	54	928	25	25,531

Figures for total use of each insecticide and regional totals were obtained from "Farmers' Use of Pesticides in 1971 - Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

/ Use of each individual insecticide, by region, is an MRI estimate.

Table C-4. MISCELLANEOUS PESTICIDES USED ON CORN, BY REGION, 1971[a,b]

(1,000 lb)

	Regions										
Pesticide	North- east	Lake States	Corn Belt	Northern Plains	Appalachian	South- east	Delta States	Southern Plains	Mountain	Pacific	Total
Dicofol	-	-	-	-	-	-	-	-	-	56	56
Other Miticides	1	-	-	-	-	-	-	-	-	-	1
Miscellaneous Fumigants	-	-	-	386	-	-	-	-	-	-	386
Total	1	0	0	386	0	0	0	0	0	0	443

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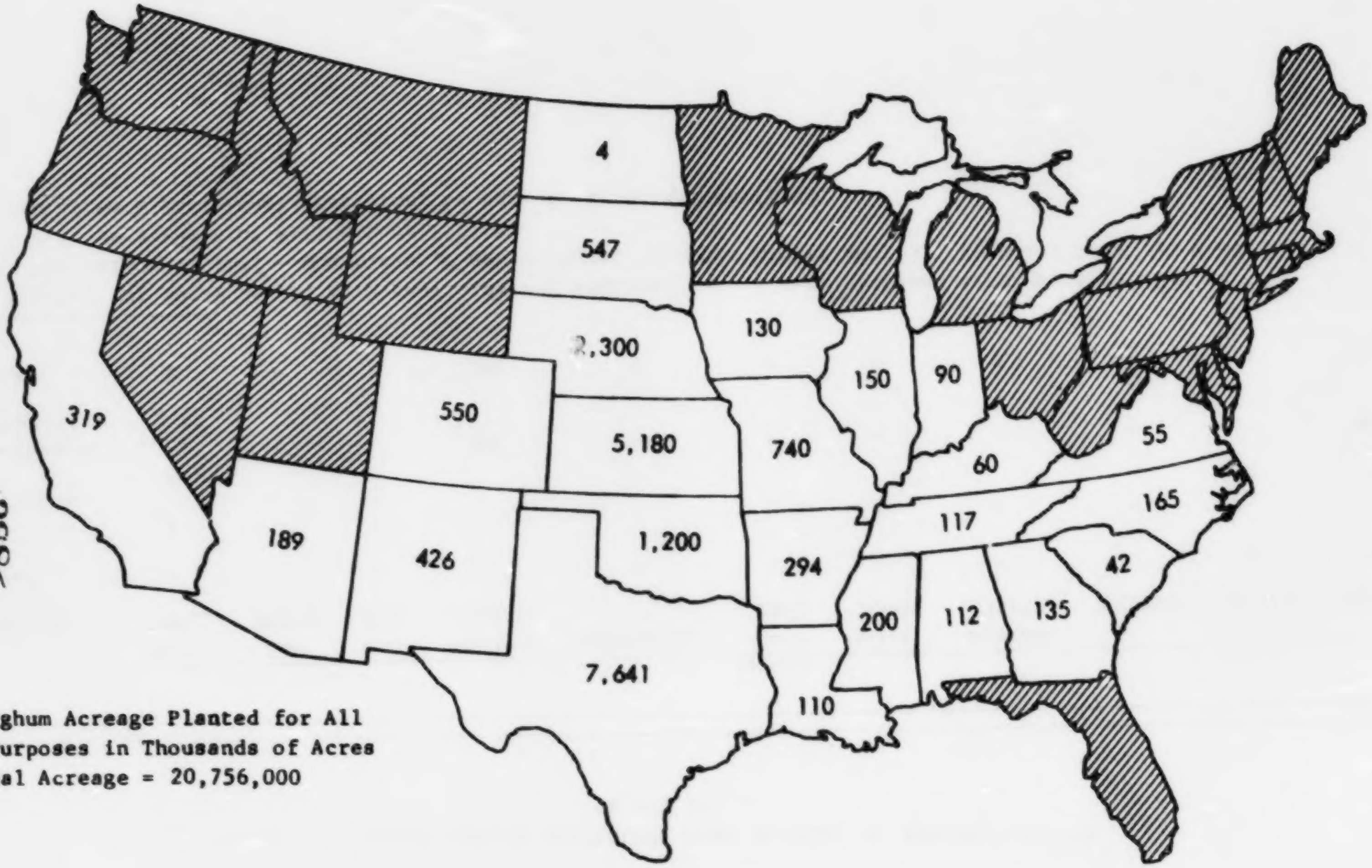
a/ Figures for total use of each pesticide and regional totals were obtained from "Farmers' Use of Pesticides in 1971 - Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

b/ Use of each individual pesticide, by region, is an MRI estimate.


4
547
2,300
130
150
90
319
550
5,180
740
60
55
165
117
189
426
1,200
294
42
200
112
135
7,641
110

Sorghum Acreage Planted for All
Purposes in Thousands of Acres
Total Acreage = 20,756,000

Figure C-3. U.S. sorghum acreage (1971), by state.

Table C-5. PESTICIDE USAGE ON U.S. SORGHUM CROP IN 1971

	By Region[a/]					
	Herbicides		Insecticides		Total Pesticides[b/]	
Region	1,000 lb	%	1,000 lb	%	1,000 lb	%
Northeast	14	0.1	--	0.0	14	0.1
Lake States	--	0.0	--	0.0	--	0.0
Corn Belt	1,176	10.2	94	1.6	1,270	7.4
Northern Plains	5,834	50.6	1,301	22.7	7,135	41.3
Appalachian	310	2.7	28	0.5	338	2.0
Southeast	125	1.1	406	7.1	531	3.1
Delta States	287	2.5	339	5.9	626	3.6
Southern Plains	3,486	30.2	2,927	51.1	6,413	37.1
Mountain	251	2.1	398	7.0	649	3.7
Pacific	55	0.5	236	4.1	291	1.7
Totals	11,538	100.0	5,729	100.0	17,267	100.0

---

a/ Source: "Farmers Use of Pesticides in 1971--Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

b/ Fungicides and miscellaneous pesticides are not listed separately in the above report, and are not included in this table.

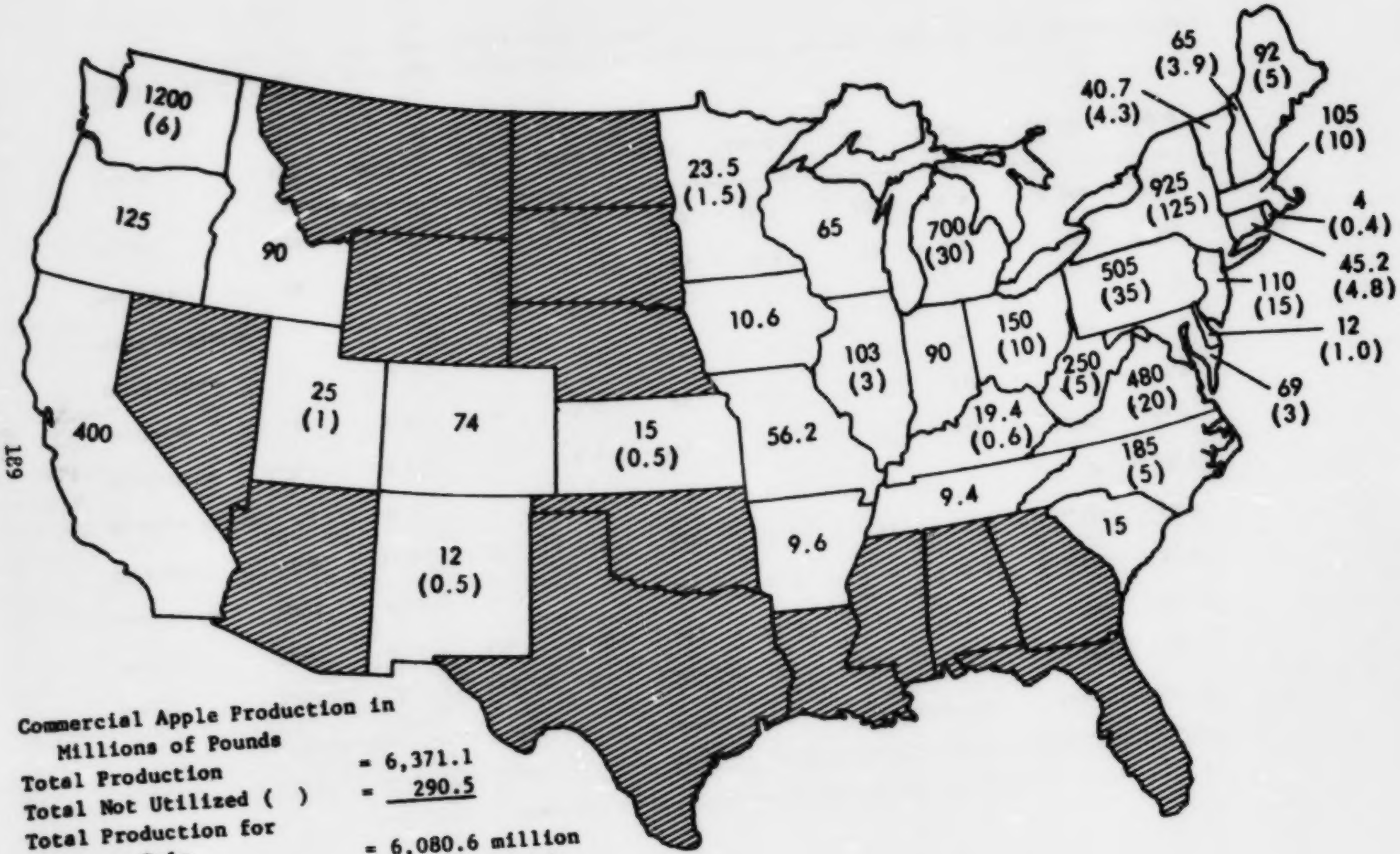
Table C-6. HERBICIDES USED ON SORGHUM, BY REGION, 1971[a,b]
(1,000 lb)

Herbicide	North-east	Lake States	Corn Belt	Northern Plains	Appa-lachian	South-east	Delta States	Southern Plains	Moun-tains	Pacific	Total
	Region										
Atrazine	5	-	400	2,600	160	75	115	700	110	10	4,175
Propazine	-	-	350	500	20	5	30	1,680	-	-	2,585
2,4-D	4	-	200	1,000	60	20	45	600	100	10	2,039
Propachlor	3	-	100	1,250	-	-	50	20	-	10	1,433
Norea	-	-	50	200	50	5	10	100	-	3	418
Arsenicals	-	-	10	-	10	10	20	100	20	15	185
MCPA	-	-	10	70	-	-	-	20	14	5	119
Others	2	-	56	214	10	10	17	266	7	2	584
Total	14	0	1,176	5,834	310	125	287	3,486	251	55	11,538

---

a/ Figures for total use of each herbicide and regional totals were obtained from "Farmers' Use of Pesticides in 1971--Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

b/ Use of each individual herbicide, by region, is an MRI estimate.


1200
(6)
125
90
400
25
(1)
74
12
(0.5)
15
(0.5)
23.5
(1.5)
10.6
56.2
9.6
65
103
(3)
700
(30)
90
150
(10)
19.4
(0.6)
9.4
250
(5)
480
(20)
185
(5)
15
505
(35)
925
(125)
40.7
(4.3)
65
(3.9)
92
(5)
105
(10)
4
(0.4)
45.2
(4.8)
110
(15)
12
(1.0)
69
(3)

Commercial Apple Production in
Millions of Pounds
Total Production = 6,371.1
Total Not Utilized ( ) = 290.5
Total Production for Use or Sale = 6,080.6 million pounds

Figure C-4. U.S. commercial apple production (1971), by state.

Table C-7. PESTICIDE USAGE ON U.S. APPLE CROP IN 1971 BY REGION

	Fungicides		Herbicides		Insecticides		Misc. Pesticides		Total Pesticides	
Region	1,000 lb	%	1,000 lb	%	1,000 lb	%	1,000 lb	%	1,000 lb	%
Northeast	2,943	40.8	128	65.0	2,403	49.8	116	21.1	5,590	43.7
Lake States	1,026	14.3	-	-	349	7.2	29	5.3	1,404	11.0
Corn Belt	853	11.8	11	5.6	831	17.2	36	6.6	1,731	13.5
Northern Plains	12	0.2	-	-	5	0.1	-	-	17	0.1
Appalachian	1,353	18.8	1	0.5	359	7.4	27	4.9	1,740	13.6
Southeast	67	0.9	6	3.0	32	0.7	7	1.3	112	0.9
Delta States	-	-	-	-	-	-	-	-	-	0
Southern Plains	-	-	-	-	-	-	-	-	-	0
Mountain	16	0.2	-	-	44	0.9	23	4.2	83	0.7
Pacific	937	13.0	51	25.9	808	16.7	310	56.6	2,106	16.5
Totals	7,207	100.0	197	100.0	4,831	100.0	548	100.0	12,783	100.0

Source: "Farmers' Use of Pesticides in 1971 Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

Table C-8. FUNGICIDES USED ON APPLES BY REGION, 1971[a,b] (1,000 lb)

Fungicide	Regions										
	North-east	Lake States	Corn Belt	Northern Plains	Appa-lachian	South-east	Delta States	Southern Plains	Moun-tain	Pacific	Total
Captan	1,250	800	400	-	900	-	-	-	2	40	3,392
Other dithio-carbamates	800	20	200	10	200	-	-	-	2	65	1,297
Dinocap, dodine, quinones	600	160	50	1	3	10	-	-	2	95	921
Other inorganics	65	-	1	-	-	15	-	-	-	460	541
Zineb	50	1	100	-	180	5	-	-	4	170	510
Other organics	80	30	5	1	9	10	-	-	1	40	176
Maneb	25	-	50	-	40	-	-	-	5	5	125
Ferbam	70	15	-	-	20	5	-	-	-	8	118
Other copper compounds	1	-	45	-	-	15	-	-	-	50	111
Copper sulfate	2	-	2	-	1	7	-	-	-	4	16
Total	2,943	1,026	853	12	1,353	67	0	0	16	937	7,207

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a/ Figures for total use of each fungicide and regional totals were obtained from "Farmers' Use of Pesticides in 1971--Quantities," Agricultural Economic Report No. 252, Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974).

b/ Use of each individual fungicide, by region, is an MRI estimate.

Table C-9. INSECTICIDES USED ON APPLES BY REGION, 1971[a,b] (1,000 lb)

Insecticide	North-east	Lake States	Corn Belt	Northern Plains	Appa-lachian	South-east	Delta States	Southern Plains	Moun-tain	Pacific	Total
Inorganics	900	10	500	-	140	3	-	-	-	300	1,853
Azinphosmethyl	500	100	60	-	100	7	-	-	2	200	969
Other Organophosphorus	300	80	35	1	40	2	-	-	3	160 180	641
Carbaryl	300	100	100	-	30	1	-	-	2	50	583
Chlordane	200	50	100	-	10	2	-	-	4	7	373
Parathion	60	5	10	3	15	5	-	-	15	25	138
Endosulfan	100	2	10	-	10	2	-	-	10	2	136
Ethion	35	-	-	-	1	5	-	-	3	25	69
Malathion	-	-	5	-	10	2	-	-	-	4	21
Diazinon	6	2	4	1	-	-	-	-	-	5	18
Bidrin	-	-	4	-	2	-	-	-	3	3	12
Methoxychlor	1	-	2	-	1	-	-	-	1	2	7
Dieldrin	1	-	-	-	-	-	-	-	1	3	5
Other Organochlorine	-	-	-	-	-	-	-	-	-	2	2
Endrin	-	-	-	-	-	2	-	-	-	-	2
TDE (DDD)	-	-	-	-	-	1	-	-	-	-	1
Heptachlor	-	-	1	-	-	-	-	-	-	-	1
Total	2,403	349	831	5	359	32	0	0	44	808	4,831

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a/ Figures for total use of each insecticide and regional totals were obtained from "Farmers' Use of Pesticides in 1971--Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

b/ Use of each individual insecticide, by region, is an MRI estimate.

Table C-10. **HERBICIDES USED ON APPLES BY REGION, 1971**[a,b]
(1,000 lb)

	Regions										
Herbicide	**North-east**	**Lake States**	**Corn Belt**	**Northern Plains**	**Appa-lachian**	**South-east**	**Delta States**	**Southern Plains**	**Moun-tain**	**Pacific**	**Total**
Other Organic	65	-	1	-	1	-	-	-	-	28	95
Simazine	20	-	5	-	-	1	-	-	-	10	36
Dalapon	25	-	1	-	-	3	-	-	-	5	34
2,4-D	15	-	3	-	-	1	-	-	-	4	23
Dinitro Group	2	-	-	-	-	1	-	-	-	3	6
Diuron	1	-	-	-	-	-	-	-	-	1	2
Trifluralin	-	-	1	-	-	-	-	-	-	-	1
Total	128	0	11	0	1	6	0	0	0	51	197

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[a] Figures for total use of each herbicide and regional total were obtained from "Farmers' Use of Pesticides in 1971-Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

[b] Use of each individual herbicide, by region, is an MRI estimate.

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Table C-11. MISCELLANEOUS PESTICIDES USED ON APPLES BY REGION, 1971[a,b]
(1,000 lb)

Pesticide	North-east	Lake States	Corn Belt	Northern Plains	Appa-lachian	South-east	Delta States	Southern Plains	Moun-tain	Pacific	Total
Miticides											
Dicofol	1	-	-	-	-	-	-	-	2	3	6
Omite	69	10	28	-	9	-	-	-	2	160	278
Others	32	-	-	-	10	2	-	-	9	30	83
Fumigants	-	-	-	-	-	-	-	-	-	-	0
Defoliants and Desiccants	-	-	-	-	-	-	-	-	-	-	0
Rodenticides	5	-	-	-	-	-	-	-	-	2	7
Plant Growth Regulators	9	19	8	-	8	5	-	-	10	115	174
Repellents	-	-	-	-	-	-	-	-	-	-	0
Total	116	29	36	0	27	7	0	0	23	310	548

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a/ Figures for total use of each pesticide and regional totals were obtained from "Farmers' Use of Pesticides in 1971-Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

b/ Use of each individual insecticide, by region, is an MRI estimate.

APPENDIX D

PESTICIDE APPLICATION RATES RECOMMENDED BY THE USDA AND MANUFACTURERS' PRODUCT LABELS

Table D-1. USDA RECOMMENDED PESTICIDE APPLICATION RATES

	Apples lb AI/acre[a]	Corn lb AI/acre[a]	Sorghum lb AI/acre[a]
HERBICIDES			
Alachlor		3.5 preplant 4.0 preemergence	
Atrazine		4.0 preplant, preemergence and postemergence	4.0 preplant, preemergence and postemergence
Butylate		4.0 preplant	
Dalapon	3.7 when trees are less than 4 years old 7.4 when trees are 4 years or older	11.1 preplant fall 6.0 preplant spring 0.3 early postemergence 1.5 postemergence	6.0 preplant
2,4-D	2.0 do not allow spray to contact leaves, fruit or stem of tree	2.0 preemergence 1.5 postemergence 1.3 after early dough stage	2.0 preemergence 1.0 postemrgence 0.75 postemergence (as lithium salt)
Norea			2.4 preemergence
Propachlor		6.0 preemergence	5.25 preemergence
Propazine			3.2 preemergence

Table D-1. (Continued)

	Apples lb AI/acre[a]	Corn lb AI/acre[a]	Sorghum lb AI/acre[a]
INSECTICIDES			
Aldrin		2.0 broadcast application 1.0 preplant 0.25 (as dry bait formulation) around base of plant (30 days)[b]	2.0 oz/bushel-seed treatment
Azinphosmethyl	6.0 (7 days)[b]		
Bux		1.0 (as granular formulation)/ 13,080 ft of row or 0.4 oz/325 ft of row at planting 4.0 broadcast	
Carbaryl	12.0 (1 day)[b]	2.0 (forage) 3.0 (at time of plant)	2.0 (21 days for grain; no limit for forage)[b]
Carbofuran		1.0 3.0 (granular formulation)	
Chlordane	8.0 (30 days)[b] 10.0 (as soil preparation when no fruit is present)	2.0 2.0 oz/bushel-seed treatment)	2.0 oz/bushel-seed treatment
Diazinon®	6.0 (14 days)[b]	1.25 (spray) 1.6 (dust) 1.0 (as a spray at the base of plants at planting time) 2.0 (soil application to furrow) 5.2 (granular; at time of planting) 5.5 (spray) 10.0 preplant 2.0 oz (bushel-seed treatment)	0.5 (7 days)[b] 4.0 preplant 2.0 (granular) 2.0 oz/bushel-seed treatment

Table D-1. (Continued)

	Apples lb AI/acre[a]	Corn lb AI/acre[a]	Sorghum lb AI/acre[a]
INSECTICIDES (Continued)			
Disulfoton		1.2 oz/1,000 ft of row 1.0 (40 in. row spacing)	0.5 (spray; 40 in. row spacing) 1.2 oz/1,000 ft of row
Endosulfan	2.5 (not after hull split) 9.0 (not after petal fall) 4.0 (30 days)[b] 2.5 (30 days or 21 days)[b]		
Heptachlor		3.0 (soil only) 5.0 (soil only; peat and muck soils only)	2.0 oz/bushel-seed treatment
Malathion		1.6 (dust) (5 days)[b] 1.25 (spray) (5 days)[b]	10.0 oz/1,000 bu; mixed with grain; postharvest storage treatment only 5.0 oz/1,000 ft^2 grain surface; postharvest storage only, i.e., 0.9 (spray) (7 days)[b]
Methyl Bromide		2.0/1,000 ft^3-fumigation	4.0/1,000 ft^3-fumigation
Methyl Parathion	6.0 (14 days)[b]	0.25 (12 days)[b]	1.0 (21 days)[b]

Table D-1. (Concluded)

	Apples lb AI/acre[a]	Corn lb AI/acre[a]	Sorghum lb AI/acre[a]
INSECTICIDES (Concluded)			
Parathion	6.0 (14 days)[b]	1.0 (12 days)[b]	1.0 (12 days)[b]
Phorate		1.0 (granular; 40 in. row spacing) (30 days)[b] 2.0 oz/1,000 ft row	1.0 (granular) 1.2 oz/1,000 ft row
Toxaphene	16.0 (40 days)[b]	2.0 (granular) 6.0	2.0 (28 days)[b] 3.0 (40 days)[b] 2 oz/bushel-seed treatment
Captan	10.0 0.12% solution (postharvest)	3.2 oz/1,000 lb seed	3.0 oz/100 lb seed dry mixture 2.3 oz/100 lb seed (slurry mixture)
Dinocap[c]	3.0 (21 days)[b]		
Dodine	4.0 (7 days)[b] 1.6 (5 days)[b]		
Omite[c]	3.75 (7 days)[b]		
Sulfur	170.0		
Zineb	12.0	3.0	

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[a] Rates are expressed terms of pounds active ingredient applied per acre or in terms of ounces active ingredient.

[b] Designates number of days required between last application and harvest.

Source: USDA Summary of Registered Agricultural Pesticide Chemical Uses, Vol, I, II, and III. Pesticides Regulation Division, Agricultural Research Service, United States Department of Agriculture.

Table D-2. PESTICIDES MOST COMMONLY USED ON APPLES; APPLICATION RATES RECOMMENDED ON PRODUCT LABELS

	Manufacturer	Trade Name	Target Pest(s)	Recommended Application
Fungicides Copper Compounds	FMC Corporation	C-O-O-S® 50% copper expressed as metallics	Fire blight	1/4 lb/100 gal. water; first application when 20% of the blossoms are open, repeat when 75% are open
Dinocap	Rohm and Haas Company	Karathane® 4 lb AI/gal	Powdery mildew	4 to 6 oz/100 gal. water (500 to 800 gal. spray/acre)
		Karathane® 20% AI/lb		Spray program should be planned through Extension Service
Dithiocarbamates Coordination product of zinc and maneb	Rohm and Haas Company	Dikar® 72% AI/lb	Apple scab, powdery mildew, black rot, bitter rot, brown rot, Cedar apple rust, fly speck, sooty blotch, European red mite, Schoene mite, two-spotted mite, clover mite	On a spray schedule: 1-1/2 to 2 lb/100 gal. water Concentrate spray: 8 to 10 lb/acre for mature trees
	Rohm and Haas Company	Dithane® M-45 80% AI/lb	Bitter rot, black rot, brown rot, Cedar apple rust, fly speck, scab, sooty blotch	1 to 2 lb/100 gal. water (10 lb/acre)
Zineb	FMC Corporation	Zineb WP 75% AI/lb	Scab, sooty blotch, fly speck, Brooks spot, black rot	1 to 1-1/2 lb/100 gal. water
	Rohm and Haas Company	Dithane® Z-78 75% AI/lb	Apple blotch, bitter rot, black rot, Botryosphaeria fruit rot, Brooks spot, Cedar rust, fly speck, frogeye, scab, sooty blotch, quince rust	1 to 2 lb/100 gal. water, maximum of 10 lb/acre or 1/2 to 1 lb when used with captan or glyodin
	Rohm and Haas Company	Dithane® Z-78 75% AI/lb	Fire blight	2 lb/100 gal. water (10 lb/acre)

Table D-2. (Continued)

	Manufacturer	Trade Name	Target Pest(s)	Recommended Application Rate
Fungicides Dodine	American Cyanamid Company	Cyprex$^{\underline{R}}$ WP 65% AI/lb	Scab	Protection schedule: 1/4 to 1/2 lb/100 gal. water After infection: 3/4 lb/100 gal. water Air application: 1-1/2 lb/acre in 5 to 7 gal. water (allow 28 days before harvest)
Sulfur	FMC Corporation	Kolospray$^{\underline{R}}$ 81% AI/lb	Scab, powdery mildew	6 to 8 lb/100 gal. water or 4 to 6 plus 2 to 3 lb Polysulfide Compound/100 gal. water
	FMC Corporation	Kolo$^{\underline{R}}$ 100 75% AI/lb	Scab	3-1/2 lb/100 gal. water
	FMC Corporation	Kolodust$^{\underline{R}}$ Xtra Dust or Spray 53% AI/lb	Scab	5 to 8 lb/100 gal. water; after scab is under control, 2 to 4 lb/100 gal water
	FMC Corporation	Kolodust$^{\underline{R}}$ 84% AI/lb	Scab, powdery mildew	40 to 50 lb/acre
	Stauffer Chemical Company	Magnetic$^{\underline{R}}$ "95" 95% AI/lb	Scab, powdery mildew	6 to 8 lb/100 gal. water in prebloom, bloom, and petal fall sprays; 4 to 6 lb/100 gal. water in cover sprays
Herbicides Dalapon	Dow Chemical Company	Dowpon$^{\underline{R}}$ 74% AI/lb	Johnsongrass control in orchards	5 to 10 lb/acre under trees
Simazine	Ciba-Geigy	Princep$^{\underline{R}}$ 80W	Controls many annual weeds	2-1/2 to 5 lb/acre under trees (do not apply to sandy soil)
Nitralin (California only)	Shell Chemical Company	Planavin$^{\underline{R}}$ 75WP 75% AI/lb	Control of broadleaf weeds and grasses	2-2/3 to 5-1/3 lb/acre after harvest and before June 1 of the next year
		Planavin$^{\underline{R}}$ 4 4 lb AI/gal	Control of broadleaf weeds and grasses	4 to 8 qt/acre after harvest and before June 1 of the next year
Insecticides Azinphosmethyl	Chemagro	Guthion$^{\underline{R}}$ WP 50% AI/lb	Aphids, apple maggot, codling moth, European apple sawfly, eye-spotted bud moth, Forbes scale, fruit tree leaf roller, green fruitworm, leafhoppers, mealybug, mites, orange tortrix, pear psylla, plum curculio, Putnam scale, red-banded leaf roller, San Jose scale, stink bug,	1/2 to 5/8 lb/100 gal. water (maximum of 1,000 gal. spray/acre)

Table D-2. (Continued)

	Manufacturer	Trade Name	Target Pests(s)	Recommended Application Rate
Insecticides (Continued) Carbaryl	Union Carbide Corporation	Sevin® 80% AI/lb	Apple sucker, green apple aphid, woolly apple aphid, apple aphid, bagworm, codling moth, apple rust mite, eye-spotted bud moth, green fruitworm, Lygus bugs, orange tortrix, scales, mealybug	West of the Rocky Mountains: 1 to 1-1/4 lb/100 gal. spray; East of the Rocky Mountains: 2/3 lb/100 gal. spray (allow 1 day before harvest)
		Sevin® 50W 50% AI/lb	Apple sucker, aphids, mites, codling moth, scales, Lygus bugs, orange tortrix	West of the Rocky Mountains: 1-1/2 to 2 lb/100 gal. spray
			Mealybug, green apple, aphid, codling moth, white apple leafhopper	East of the Rocky Mountains: 1 lb/100 gal. spray
			Apple maggot, bagworm, other aphids, mites, scales	2 lb/100 gal. water (allow 1 day before harvest)
Dimethoate	American Cyanamid Company	Cygon® 25WP 25% AI/lb	Aphids, leafhoppers, mites, (except rust mites)	1 to 2 lb/100 gal. water
		Cygon® 267 2.67 lb AI/gal	Aphids, leafhoppers, mites (except rust mites)	3/4 to 1-1/2 pt/100 gal. water (allow 28 days before harvest)
Endosulfan	FMC Corporation	Thiodan® 3 Dust 3% AI/lb	Apple aphid	50 lb/acre
		Thiodan® 50WP 50% AI/lb	Apple aphid, rosy apple aphid	1 lb/100 gal. water (maximum of 4 to 5 lb/acre)
			Apple rust mite, woolly apple aphid	1 lb/100 gal water (maximum of 8 lb/acre)
Methyl Parathion	Monsanto	Niran® M-4 4 lb AI/gal	Aphids, codling moth, plum curculio, scales, red-banded leaf roller	1/2 to 1 pt/100 gal. water (maximum of 6 qt/acre)

Table D-2. (Concluded)

	Manufacturer	Trade Name	Target Pests(s)	Recommended Application Rate
Insecticides (Concluded)				
Parathion	Monsanto	Niran® E-4 4 lb AI/gal	European sawfly, scales, mealy-bugs, mites, bagworms, codling moths, leaf rollers, plum curculio	1/2 pt/100 gal. water
			Grasshoppers	3/4 pt/100 gal. water
			Bud moth, mites, aphids, leaf-hoppers, leaf miners, red bug	3/8 pt/100 gal. water (maximum of 1-1/2 gal/acre)
Miticides				
Propargite	Uniroyal Chemical	Omite® 30W 30% AI/lb	European red mite, two-spotted mite, Pacific spider mite, McDaniel mite	5 to 12 lb/acre East of Rocky Mountains: 1-1/4 to 1-1/2 lb/100 gal. water (allow 7 days before harvest)
Vendex® 50	Shell Chemical Company	Vendex® 50 50% AI/lb	European red mite, McDaniel Spider mite, two-spotted mite, apple rust mite	4 to 8 oz/100 gal. water (maximum of 800 gal. spray/acre)

Table D-3. PESTICIDES MOST COMMONLY USED ON CORN; APPLICATION RECOMMENDED ON PRODUCT LABELS

	Manufacturer	Trade Name	Target Pest(s)	Recommended Application Rate
Fungicides				
Dithiocarbamates Coordination Product of Zinc and Maneb	Rohm and Haas Company	Dithane® M-45 80% AI/lb	Helminthosporian leaf blight	1-1/2 lb/acre; minimum of 25 gal. water/acre
Zineb	FMC Corporation	Zineb WP 75% AI/lb	Helminthosporian leaf blight	1-1/2 to 2 lb/100 gal. water
Herbicides				
Alachlor	Monsanto	Lasso® II 15% AI/lb	Annual grasses, sedges, annaul broadleaves	Broadcast: 16 lb/acre Band: (40 in. row spacing) 2.8 to 4.0 lb/acre
		Lasso® 10G 10% AI/lb	Grass and weed control	Broadcast: 20 to 40 lb/acre Band (40 in. row spacing): 7.0 to 12.2 lb/acre (rate depending on soil type)
		Lasso® EC 4 lb AI/gal	Grass and weed control	Preplant: 2.5 to 3.5 qt/acre Broadcast: 2.5 to 3.5 qt/acre (rate depending on soil type)
Atrazine	Ciba-Geigy	AAtrex® 80W 80% AI/lb	Broadleaf weed and grass control	Broadcast; preplant, preemergence Postemergence: 2.5 to 3.75 lb/acre (rate depending on soil type)
		AAtrex® 4L 4 lb AI/gal	Broadleaf weed and grass control	Broadcast; preplant, preemergence Postemergence: 4 to 6 pt/acre (rate depending on soil type)
Butylate	Stauffer Chemical Company	Sutan® + 6.7 lb AI/gal	Annual and perennial grasses, broadleaf weeds	Broadcast: (sandy soil) 3-3/4 pt/acre
2,4-D	Dow Chemical Company	2,4-D (LV) 4 lb AI/gal	Weed control	Preemergence: 1 to 2 qt/acre Emergence: 1 pt/acre Postemergence: 1/2 pt/acre
		2,4-D (alkanol amine salt) 4 lb AI/gal	Weed control	Preemergence: 2 to 4 pt/acre Emergence: 1 pt/acre Postemergence to 8 in: 1/2 to 1 pt/acre 8 in. to tasseling: 1 pt/acre

Table D-3. (Continued)

	Manufacturer	Trade Name	Target Pest(s)	Recommended Application Rate
Herbicides (continued) 2,4-D (continued)	Rhodia, Chipman Division	2,4-D L.V. ester 4 lb AI/gal	Weed control	Preemergence: 1 to 2 qt in 10 to 20 gal. water/acre; on muck and clay soil, 1/2 to 1 gal/acre Postemergence: 1/2 to 3/4 pt/acre With Nitrogen: 2/3 to 1 pt/acre with 80 to 120 lb nitrogen
		2,4-D amine No. 4 4 lb AI/gal	Weed control	1/2 to 1 pt/acre
	Transvaal, Inc.	Weed-Rhap[f] A-4D 2,4-D amine 4 lb AI/gal	Weed control	1 pt in 5 to 10 gal. water/acre
		Weed-Rhap[f] B-6D 6 lb AI/gal butyl ester of 2,4-D	Weed control	1/3 pt in 5 to 10 gal. water/acre Preemergence: 1.3 to 2.6 pt in 5 to 10 gal. water/acre
		Weed-Rhap[f] LV-6D 6 lb AI/2,4-D/gal	Weed control	1/3 pt in 5 to 10 gal. water/acre
Propachlor	Monsanto	Ramrod[f] 65 65% AI/lb	Selective preemergence weed control	Broadcast: 6 to 9 lb in 20 gal. water/acre (rate depending on soil type) Preemergence: 6 to 9 lb in 8 gal. water/acre
		Ramrod[f] 20G 20% AI/lb	Selective preemergence weed control	Broadcast: 20 to 30 lb/acre Band (40 in. row spacing): 7.0 to 10.5 lb/acre
		Ramrod[f]/atrazine 69% AI/lb	Selective preemergence weed control	Broadcast: 5 to 8 lb in 20 gal. water (minimum)/acre Band: 5 to 8 lb in 8 gal. water (minimum)/acre

Table D-3. (Continued)

	Manufacturer	Trade Name	Target Pest(s)	Recommended Application Rate
Insecticides				
Aldrin	Shell Chemical Company	Aldrin 4 lb AI/gal	Rootworm, diabrotica larvae	Broadcast: 1 qt/acre
			Annual grubs, ants, cutworms, false wireworms, fleabeetle larvae, Japanese beetle grub, seed-corn beetle and maggot, wireworms, European chafer grub, grape colaspis, white grubs	Broadcast: 1-1/2 to 2 qt/acre Band: 1 qt/acre Broadcast: 3 qt/acre Band: 1 qt/acre
		Aldrin 20G 20% AI/lb	Rootworm, diabrotica larvae	Band: 5 lb/acre
			Annual grubs, ants, cutworms, false wireworms, fleabeetle larvae, Japanese beetle grub, seed-corn beetle and maggot, wireworms, European chafer grub, grape colaspis, white grubs	Broadcast: 7-1/2 to 10 lb/acre Band: 5 lb/acre Broadcast: 15 lb/acre
Bux	Chevron, Ortho Division	BUX® Ten 10G 10% AI/lb	Corn Rootworm	7.5 to 10 lb/acre (40 in. row spacing)
Carbaryl	Union Carbide	Sevin® 50W 50% AI/lb	Corn earworm, corn rootworm adults, European corn borer, fall armyworm, flea beetle, Japanese beetle, sap beetle, leafhoppers	2 to 4 lb/acre
			Cutworm	4 lb in 50 gal. water (minimum)/acre
		Sevin® sprayable 80% AI/lb	Corn earworm, corn rootworm adults, European corn borer, fall armyworm, flea beetle, Japanese beetle, leafhoppers	1-1/4 to 2-1/2 lb/acre
			Cutworm	2-1/2 lb in 15 gal. water (minimum)/acre
		Sevimol® 4 4 lb AI/gal	Corn earworm, corn rootworm adults, grasshoppers, European corn borer, Southwestern corn borer, fall armyworm, flea beetles, Japanese beetle, sap beetle	1-1/2 qt/acre
			Western bean cutworm	2 qt/acre
Carbofuran	FMC Corporation	Furadan® 4 flowable 4 lb AI/gas	Corn rootworm	1-1/2 to 2 pt/acre at plant (40 in. row spacing)

Table D-3. (Continued)

	Manufacturer	Trade Name	Target Pest(s)	Recommended Application Rate
Insecticides (continued) Carbofuran (continued)		Furadan^{R} 10 Granules 10% AI/lb	Corn rootworm, flea beetles, European corn borer, stalk rot (decrease insect wounds), armyworm, fall armyworm, Northern, Western, and European corn rootworms	Plant, post plant, and foliar: 7-1/2 to 10 lb/acre (40 in. row spacing)
			Southwestern corn borer (2nd and 3rd generation)	15 to 30 lb/acre at plant
			European corn borer (1st generation), wireworms	20 to 30 lb/acre at plant (40 in. row spacing)
			Nematodes	15 to 20 lb/acre at plant (40 in. row spacing)
Diazinon^{R}	Ciba-Geigy	Diazinon^{R} AG500 4 lb AI/gal	Corn rootworm adults	1/2 to 1 pt/acre
			Corn leaf aphids	1 to 2 pt/acre
			Mites, flea beetles, grasshoppers	1 pt/acre
			Sap beetles	2 to 2-1/2 pt/acre (aerial: minimum of 1 gal. water/acre) (ground: minimum of 5 gal. water/acre)
		Diazinon^{R} 50W 50% AI/lb	Corn rootworm larvae	Postemergence basal treatment: 1 to 2 lb/acre (40 in. row spacing)
			Seed corn maggot, cutworms	Broadcast: 4 to 8 lb/acre prior to plant
			Wireworms	6 to 8 lb/acre
			Corn leaf aphid	1 to 2 lb/acre
			Grasshoppers	1 lb/acre
			Sap beetle	2 to 2-1/2 lb/acre plus 1 to 2 gal. soluble mineral oil/acre
		Diazinon^{R} 14G 14% AI/lb	Corn rootworm larvae, lesser cornstalk borers	Postemergence basal treatment: 3-1/2 to 7 lb/acre (40 in. row spacing)
			European corn borers, fall armyworms, Southwestern corn borers	7 to 14 lb/acre
			Cutworms, seed corn maggots	Broadcast: 14 to 28 lb/acre
			Garden symphylans (centipedes)	Broadcast: 70 lb/acre
			Wireworms	Broadcast: 21 to 28 lb/acre

Table D-3. (Concluded)

	Manufacturer	Trade Name	Target Pest(s)	Recommended Application Rate
Insecticides (continued) Parathion	Monsanto	Niran® E-4 4 lb AI/gal	European corn borer	1 pt/acre
			Corn leaf aphids	1/2 pt/acre
			Fall armyworms, corn earworms, corn rootworm adults, armyworms to third instar, climbing cutworms, grasshoppers, Japanese beetles	3/4 pt/acre
			Stink bugs, spider mites	1 pt/acre
			Chinch bugs	1-1/2 pt/acre
	Kerr-McGee Chemical Corporation	Parathion Granular-4 4% AI/lb	Wireworms	25 lb/acre in furrow at plant
Phorate	American Cyanamid Company	Thimet® 10G 10% AI/lb	Corn rootworms,	10 lb/acre (40 in. row spacing)
			European corn borer (1st generation)	10 lb/acre (40 in. row spacing) (allow 30 days before harvest)
		Thimet® 15G 15% AI/lb	Corn rootworms,	6.5 lb/acre (40 in. row spacing)
			European corn borer (1st generation)	6.5 lb/acre (40 in. row spacing) (allow 30 days before harvest)

Table D-4. PESTICIDES MOST COMMONLY USED ON SORGHUM; APPLICATION RECOMMENDED ON PRODUCT LABELS

Herbicides	Manufacturer	Trade Name	Target Pest(s)	Recommended Application Rate
Atrazine	Ciba-Geigy	AAtrex® 80W 80% AI/lb	Broadleaf weed and grass control (medium and fine textured soils only)	Broadcast preplant and preemergence: 2 to 3 lb/acre (rate depending on soil type) broadcast, postemergence: 2.5 to 3.75 lb/acre (rate depending on soil type)
		AAtrex® 4L 4 lb AI/gal	Broadleaf weed and grass control (medium and fine textured soils only)	Broadcast, preplant and preemergence: 3.2 to 4.75 pts/acre (rate depending on soil type) broadcast, postemergence: 4 to 6 pts/acre (rate depending on soil type)
2,4-D	Dow Chem. Co.	2,4-D (LV) 4 lb AI/gal	Weed control	Postemergence: 1/2 pt/acre
		2,4-D (alkanol amine salt) 4 lb AI/gal	Weed control	Postemergence: 2/3 to 1 pt/acre
	Rhodia Chipman Div.	2,4-D Amine No. 4 4 lb AI/gal	Weed control	Postemergence: 1 pt/acre
2,4-D	Transvaal, Inc.	Weed-Rhap® A-4D 4 lb AI 2,4-D amine/gal	Weed control	1 pt in 5 to 10 gal water/acre
		Weed-Rhap® B-6D 6 lb AI butyl ester of 2,4-D/gal	Weed control	1/3 pt in 5 to 10 gal. water/acre

Table D-4. (Continued)

Herbicides	Manufacturer	Trade Name	Target Pest(s)	Recommended Application Rate
2,4-D continued	Transvaal, Inc	Weed-Rhap® LV-6D 6 lb AI/gal	Weed control	1/3 pt in 5 to 10 gal. water/acre
Propachlor	Monsanto	Ramrod® 65 WP 65% AI/lb	Selective preemergence weed control	Broadcast: 6 to 7.5 lb in 20 gal. water (minimum) per acre, band: 2 to 2.5 lb in 8 gal. water (minimum) per acre (40 in. row spacing)
		Ramrod® 20 G 20% AI/lb	Selective preemergence weed control	Broadcast: 20 to 25 lb/acre band: 7.0 to 8.8 lb/acre (40 in. row spacing)
		Ramrod®/ atrazine 69% AI/lb	Selective preemergence weed control	Broadcast: 5 to 8 lb in 20 gal. water (minimum) per acre
Propazine	Ciba-Geigy	Milogard® 80 W 80% AI/lb	Broadleaf weed and grass control (not for use on sandy or loamy sand soils)	Preplant and preemergence: 1-1/2 to 4 lb/acre (rate depending on state and soil type)
Insecticides				
Carbaryl (old label)	Union Carbide Corp.	Sevin® Sprayable 80% AI/lb	Armyworms, corn earworm, stink bugs, webworms	1-1/4 to 2-1/2 lb/acre
			sorghum midge	1-7/8 lb/acre
			cutworm	2-1/2 lb/acre (allow 21 days before harvest)
		Sevin® 50-W 50% AI/lb	Armyworms, corn earworm, stink bugs, webworms	2 to 4 lb/acre
			sorghum midge	3 lb/acre
			cutworm	4 lb/acre (allow 21 days before harvest)

Table D-4. (Continued)

Insecticides	Manufacturer	Trade Name	Target Pest(s)	Recommended Application Rate
Carbaryl continued	Union Carbide Corp.	Sevimol® 4 4 lb AI/gal	Armyworms, corn earworm, stink bugs, webworms sorghum midge Southwestern corn borer cutworm	1 to 2 qt/acre 1-1/2 qt/acre 2 qt/acre (allow 21 days before harvest)
Disulfoton	Chemagro	Di-Syston® 15G 15% AI/lb	Aphids (greenbugs)	5 to 6.7 lb/acre (40 in. row spacing) (allow 30 days before harvest)
		Di-Syston® 6 lb AI/gal	Aphids (greenbugs), sorghum midge in some states	1/3 to 2/3 pt/acre (allow 30 days before harvest)
		Di-Syston® 10% AI/lb	Aphids (greenbugs)	7-1/2 to 10 lb/acre (40 in. row spacing) (allow 30 days before harvest)
Methyl Parathion	Monsanto	Niran® M-4 4 lb AI/gal	Corn leaf aphids, mites sorghum midge	1 pt/acre 1 pt to 1 qt/acre (allow 21 days before harvest)
Parathion	Monsanto	Niran® E-4 4 lb AI/gal	Sorghum midge cornleaf aphids, mites sorghum webworm, fall armyworms, armyworms to third instar, corn earworms	1 pt to 1 qt/acre 1/2 pt/acre 3/4 to 1 pt/acre (allow 21 days before harvest)
Phorate	American Cyanamid Company	Thimet® 600 6 lb AI/gal	Aphids (greenbugs)	2/3 to 1-1/3 pt/acre (allow 28 days before harvest)

Table D-4. (Concluded)

Insecticides	Manufacturer	Trade Name	Target Pest(s)	Recommended Application Rate
Toxaphene	Hercules, Inc.	Toxaphene dust 20% AI/lb	Cutworm, corn earworm armyworms, grasshoppers	7-1/2 to 15 lb/acre (allow 28 days before harvest)
		Toxaphene 60% E.C. 6 lb AI/gal	Armyworms, cutworms	1-1/2 to 2 qt/acre (allow 40 days before harvest)

APPENDIX E

EXTENSION SERVICE RECOMMENDED PESTICIDE APPLICATION RATES FOR APPLES, CORN, AND SORGHUM IN SELECTED STATES

PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop : SORGHUM
Type of Pesticide: Insecticides
Year : 1974
State: COLORADO

Pesticide[a]/	Target Pest(s)[b]/	Pound Active Ingredient Per Acre — Recommended — By Extension Service	By Suppliers	Generally Used by Growers	Minimum Effective Rate
PARATHION	APHIDS & MITES	0.5 LB	0.5	0.5	0.33
DISYSTON	"	0.5 LB	0.5	0.5	0.5
DIMETHOATE	"	- 3/4-1 1/2 PINT (FORMULATION)	SAME	SAME	3/4 PT.
THIMET	"	1 LB.	1 LB.	1 LB.	3/4 LB.
TOXAPHENE	APHIDS GRASSHOPPERS	1.5 LBS.	1.5 LBS.	1.5 LBS.	1.3 LBS.

Total Acreage Versus Acreage Treated with Insecticides in the State

Approximate number of acres in your state (1974) - 560,000
- Planted: 560,000
- Harvested for grain: 400,500
- Needing insecticide/treatment: 35,000
- Actually treated at least once with any insecticide 35,000

1/ Please list the insecticides (four or five) most frequently used on sorghum in your state, in decreasing order of volume of use.

2/ Please list the most important insects , in decreasing order of importance, against which the listed pesticides are recommended and used.

PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop Sorghum

Type of Pesticide: Herbicide

Year : 1974

State: Colorado

		Pound Active Ingredient Per Acre			
		Recommended			
Pesticide[a]	Target Pest(s)[b]	By Extension Service	By Suppliers	Generally Used by Growers	Minimum Effective Rate
propazine	annual broadleaf and some grass weeds	2 lbs	2 lbs	2 lbs	2 lbs
terbutryne	"	2 lbs	2 lbs	2 lbs	2 lbs
propachlor	annual grasses and some broadleaf weeds	5.8 lbs	5.2 lbs	5.2 lbs	5.2 lbs
2.4-D	annual broadleaf weeds	1/2 lb	1/2 lb	3/8 lb	3/8 lb

This will vary with soil type and weather conditions

Total Acreage Versus Acreage Treated with Herbicides in the State

Approximate number of acres in your state (1974) -

- Planted: 480,000
- Harvested for grain: 285,000
- Needing herbicide treatment: 80,000
- Actually treated at least once with any herbicide: 50,000

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[1] Please list the herbicides (four or five) most frequently used on sorghum in your state, in decreasing order of volume of use.

[2] Please list the most important weeds, in decreasing order of importance, against which the listed pesticides are recommended and used.

PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop : Corn
Type of Pesticide: Insecticides
Year : 1974
State: Georgia

		Pound Active Ingredient Per Acre			
		Recommended			
Pesticide[a]	Target Pest(s)[b]	By Extension Service	By Suppliers	Generally Used by Growers	Minimum Effective Rate
Parathion	corn earworm, Armyworm, Fall armyworm (in whorl)	0.25	0.25	0.25	0.25
Carbaryl	(Same group)	1.6	1.6	1.6	1.6
Toxaphene	(Same group)	2.0	2.0	2.0	2.0
Aldrin	Billbugs, Sugarcane beetle	2.0	2.0	2.0	2.0

Total Acreage Versus Acreage Treated with Insecticides in the State

Approximate number of acres in your state (1974) -

- Planted: 2,000,000
- Harvested for grain: 1,800,000
- Needing insecticide treatment: 100,000
- Actually treated at least once with any insecticide : 50,000

1/ Please list the insecticides, ; (four or five) most frequently used on corn, in your state, in decreasing order of volume of use.

2/ Please list the most important insects, , in decreasing order of importance, against which the listed pesticides are recommended and used.

PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop Corn :

Type of Pesticide: Herbicide

Year : 1974

State: Ill.

depends if used in comb. or not.

Depends on soil O.M. and weed species and weather

		Pound Active Ingredient Per Acre			
		Recommended			
Pesticide[a]/	Target Pest(s)[b]/	By Extension Service	By Suppliers	Generally Used by Growers	Minimum Effective Rate
atrazine	weeds	Ext Serv.	ask them	1-5#	1#
butylate	see 1975	doesn't	or see	3-4#	3#
alachlor	Guide	"rec."	labels	1-3#	1#
propachlor				4#	3#
2,4-D				1/4# ester 1/2# amine	

Total Acreage Versus Acreage Treated with Herbicides in the State

Approximate number of acres in your state (1974) - 10 mill approx of corn

- Planted: " "
- Harvested for grain: almost all
- Needing herbicide treatment: on what basis? all of it has weeds
- Actually treated at least once with any herbicide: 90%

1/ Please list the herbicides (four or five) most frequently used on corn in your state, in decreasing order of volume of use.

2/ Please list the most important weeds, in decreasing order of importance, against which the listed pesticides are recommended and used.

PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop CoRN :

Type of Pesticide: Insecticides

Year : 1974

State: Illinois

Pound Active Ingredient Per Acre - Based on 40" Rows

		Suggested ~~Recommended~~				
Pesticide 1/	Target Pest(s) 2/	By Extension Service	By Suppliers	Generally Used by Growers	Minimum Effective Rate Ⓒ	
Aldrin *	Cutworms, wireworms	1.0 to 1.5 *	1.0 to 1.5	1.0 to 1.5	1.0 to 1.5	
Furadan Ⓐ	Rootworms	.75 to 1.0	.75 to 1.0	.75 to 1.0	.75	
Thimet Ⓑ	Rootworms	1.0	.75 to 1.0	1.0	1.0	
Dyfonate Ⓐ	Rootworms	1.0	.75 to 1.0	1.0	1.0	
Carbaryl Ⓐ	Earworm on Sweetcorn	2.0	2.0	2.0	2.0	
carbaryl	foliage feeders	.75 to 1.5	.75 to 1.5	.75 to 1.5	.75 to 1.5 Ⓑ	
Bait *	cutworms, wireworms	2 to 4	2 to 4	2 to 4	2 to 4 Ⓒ	
Heptachlor *	"	1 to 1.5	1 to 1.5	1 to 1.5	1 to 1.5 Ⓒ	

Total Acreage Versus Acreage Treated with Insecticides in the State

Approximate number of acres in your state (1974) -

- Planted: 10,680,000
- Harvested for grain: 10,340,000
- Needing insecticide treatment: 2,700,000
- Actually treated at least once with any insecticide 6,651,000

1/ Please list the insecticides, (four or five) most frequently used on corn in your state, in decreasing order of volume of use.

2/ Please list the most important insects , in decreasing order of importance, against which the listed pesticides are recommended and used.

* Extension Entomologists in Illinois have not suggested the chlorinated hydrocarbons for several years

A- Multiple applications needed Ⓑ Depends on insect problem Ⓒ Depends on method of application

PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop : Corn

Type of Pesticide: Insecticide

Year : 1974

State: Indiana

		Pound Active Ingredient Per Acre			
		Recommended			
Pesticide[a/]	Target Pest(s)[b/]	By Extension Service	By Suppliers	Generally Used by Growers**	Minimum Effective Rate**
Aldrin	NCR	1	1/2-1*	1	1
	Cutworms Wireworms	2	1-2*	1-2*	1-2*
Chlordane	NCR	Not Rec.	1-2*	1-2*	—
	Cutworms	4	2½-4	4	--
	Wireworms	4	2-4*	4	--
Furadan®	W & NCR	3/4	3/4-1	1	3/4
Thimet®	W & NCR	1	1	1	1
Dyfonate®	W & NCR	1	3/4-1	1	1
	Wireworms	4	4	4	4

Total Acreage Versus Acreage Treated with Insecticides in the State

Approximate number of acres in your state (1974) -

- Planted: 5.6 million
- Harvested for grain: 5.5 million
- Needing insecticide treatment: [illegible].3 million**
- Actually treated at least once with any insecticide : 2.6 million**

1/ Please list the insecticides (four or five) most frequently used on corn . in your state, in decreasing order of volume of use.

2/ Please list the most important insects , in decreasing order of importance, against which the listed pesticides are recommended and used.

* Depending on application method.

** Estimate

PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop : Corn
Type of Pesticide: Herbicide
Year : 1974

State: Iowa.

		Pound Active Ingredient Per Acre			
		Recommended			
Pesticide[a/]	Target Pest(s)[b/]	By Extension Service	By Suppliers	Generally Used by Growers	Minimum Effective Rate
AATrex	Broadleaf weeds	2½-3 lbs	Same	Same	2 lbs
Lasso®	grass	2-3 lbs.	↓	↓	2 "
Sutan®	grass	3-4 lbs.	↓	↓	3 "
2,4-D	Broadleaf weeds	¼-½ lbs.	↓	↓	¼ "
Bladex®	Broadleaf weeds	2-4 lbs.	↓	↓	2 "

Total Acreage Versus Acreage Treated with Herbicides in the State

Approximate number of acres in your state (1974) -

- Planted: 12,705
- Harvested for grain: 11,850
- Needing herbicide treatment: 10,665 est
- Actually treated at least once with any herbicide: 10,665 est

---

1/ Please list the herbicides (four or five) most frequently used on corn, in your state, in decreasing order of volume of use.

2/ Please list the most important weeds, in decreasing order of importance, against which the listed pesticides are recommended and used.

PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop Corn :

Type of Pesticide: Insecticide

Year : 1974

State: Iowa

		Pound Active Ingredient Per Acre			
		Recommended			
Pesticide[a]	Target Pest(s)[b]	By Extension Service	By Suppliers	Generally Used by Growers	Minimum Effective Rate
★ aldrin &	Bl Cutworm	1 + 2	1 + 2	1 + 2	1 + 2
★★ heptachlor	wireworm	1 + 2	1 + 2	1 + 2	1 + 2
Furadan®	rootworms	1	3/4 ± 1	3/4 ± 1	1
Thimet®	rootworms	1	1	1	1

Total Acreage Versus Acreage Treated with Insecticides in the State

Approximate number of acres in your state (1974) - 12,000,000

- Planted: 12,000,000

- Harvested for grain: 11,000,000

- Needing insecticide treatment: 4,000,000

- Actually treated at least once with any insecticide : 5,250,000

★★ heptachlor is used on about 18-20% of the acres treated with chlorinated hydrocarbon insecticides.

★ 1+2 refers to 1 lb row treatment, + 2 lbs broadcast. Heptachlor would be all 1 lb row; aldrin would be 50% 1 lb row + 50% 2 lb broadcast.

---

a/ Please list the insecticides, (four or five) most frequently used on corn, in your state, in decreasing order of volume of use.

b/ Please list the most important insects, , in decreasing order of importance, against which the listed pesticides are recommended and used.

PESTICIDE APPLICATION DATA

Return to:

Return to: Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop : Corn

State: MINN.

Type of Pesticide: Herbicides

Year : 1974

		Pound Active Ingredient Per Acre			
		Recommended			
Pesticide[a]	Target Pest(s)[b]	By Extension Service	By Suppliers	Generally Used by Growers	Minimum Effective Rate
Atrazine	Grassy and Broadleaved weeds	1-3	Probably	1.6	Depends on Kind of weeds, size of weeds, soil Type, weather conditions
2,4-D	Broadleaved weeds	1/6-1	Same as	0.5	
Ramrod®	Annual grasses	4-5	Extension	a 4.5	
Lasso®	Annual grasses	2-3.9		2.1	
Banvel®	Broadleaved weeds	1/8-1/4 post 1/2 pre		0.2	

Total Acreage Versus Acreage Treated with Herbicides in the State

Approximate number of acres in your state (1974)

- Planted: 6,180,000
- Harvested for grain: 5,810,000
- Needing herbicide treatment: 98%
- Actually treated at least once with any herbicide: 95%

1/ Please list the herbicides (four or five) most frequently used on corn in your state, in decreasing order of volume of use.

2/ Please list the most important weeds, in decreasing order of importance, against which the listed pesticides are recommended and used.

PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop Sorghum :

Type of Pesticide: Herbicide

Year 1973 :

State: Mo.

		Pound Active Ingredient Per Acre			
		Recommended			
Pesticide[a]/	Target Pest(s)[b]/	By Extension Service	By Suppliers	Generally Used by Growers	Minimum Effective Rate
Atrazine (Aatrex®)	Annual weed Broad-leaf	2 lb	2 lb	2 lb	2 lb
Milogard®	Broad-leaf & grass	2.5-3 lb	2.5-3.0	2.5-3.0	2.5 lb
Ramrod®	grass	4 lb.	4 lb	4 lb	4 lb
2,4-D	Broad leaf annual weeds	$\frac{1}{2}$ lb.	$\frac{1}{2}$ lb	$\frac{1}{2}$ lb	$\frac{1}{4}$ lb.

Total Acreage Versus Acreage Treated with Insecticides/Herbicides in the State

Approximate number of acres in your state (1974) -

- Planted: 550,000 1974
- Harvested for grain: not available
- Needing herbicide treatment: 550,000
- Actually treated at least once with any herbicide: 241,000 acre 1973

1/ Please list the herbicides (four or five) most frequently used on sorghum in your state, in decreasing order of volume of use.

2/ Please list the most important - weeds, in decreasing order of importance, against which the listed pesticides are recommended and used.

PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop Corn :

State: Missouri

Type of Pesticide: Herbicide

Year ~~1974~~ 1973 : 1974 '74 info. relative to herbicide applied is not yet available

Corn

Pesticide[1]	Target Pest(s)[2]	Pound Active Ingredient Per Acre: Recommended: By Extension Service	Pound Active Ingredient Per Acre: Recommended: By Suppliers	Pound Active Ingredient Per Acre: Generally Used by Growers	Pound Active Ingredient Per Acre: Minimum Effective Rate
Aatrex®	annual weeds Broad-leaved	2-3 lb	2-3 lb	2-3 lb	2 lb.
2,4-D	Broad-leaved	1/4 - 1/2	1/4 - 1/2	1/4 - 1/2	(1/4) - 1/2
Lasso®	grasses	2-3 qt	2-3 qt	2-3 qt	2 qt
Ramrod®	grasses	4 lb	4 lb	4 lb	4 lb
Sutan+®	grasses + sedges	3 lb	3 lb	3 lb	3 lb.

Total Acreage Versus Acreage Treated with Herbicides in the State

Approximate number of acres in your state (1974) - 8,000,000 acres planted to row crops
- Planted:
- Harvested for grain: not available to date
- Needing herbicide treatment:
- Actually treated at least once with any herbicides 6,700,000

---

[1] Please list the herbicides (four or five) most frequently used on corn, in your state, in decreasing order of volume of use.

[2] Please list the most important weeds, in decreasing order of importance, against which the listed pesticides are recommended and used.

PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop : Corn

Type of Pesticide: Insecticides

Year : 1974

State: Missouri

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		Pound Active Ingredient Per Acre			
		Recommended			
Pesticide[a/]	Target Pest(s)[b/]	By Extension Service	By Suppliers	Generally Used by Growers	Minimum Effective Rate
aldrin	Cutworms and/ wireworms	1.5-2.0	unknown	unknown	Ext. Ser. Rec.
carbofuran	Rootworms	1.0	"	"	
toxaphene	Complex of above ground feeders	1.5G 1.5-3.0S	"	"	
phorate	Rootworms	1.0	"	"	
carbaryl	Complex of above ground feeders	1.5 G 1.0-2.0 S	"	"	

Total Acreage Versus Acreage Treated with Insecticides/ in the State

Approximate number of acres in your state (1974) -

- Planted: Data not released yet by USDA-Statistical Reporting Service
- Harvested for grain:
- Needing insecticide treatment: unknown
- Actually treated at least once with any insecticide : unknown

---

1/ Please list the insecticides (four or five) most frequently used on corn in your state, in decreasing order of volume of use.

2/ Please list the most important insects, in decreasing order of importance, against which the listed pesticides are recommended and used.

PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop : Sorghum State: Missouri

Type of Pesticide: Insecticide

Year : 1974

		Pound Active Ingredient Per Acre			
		Recommended			
Pesticide[a]	Target Pest(s)[b]	By Extension Service	By Suppliers	Generally Used by Growers	Minimum Effective Rate
Toxaphene	Corn earworm	2.0	Unknown	Unknown	Ext. Ser. Rec.
	Fall armyworm	1.5 G 2.0 S			
parathion	Greenbugs	0.375	"	seldom used by growers	"
	Midge	0.5			
diazinon	Midge	0.5	"	"	"
malathion	Greenbugs	15 ozs.	"	"	"

Total Acreage Versus Acreage Treated with Insecticides in the State

Approximate number of acres in your state (1974) -
- Planted: by USDA-Statistical Reporting Service Data not released yet
- Harvested for grain:
- Needing insecticide treatment: unknown
- Actually treated at least once with any insecticide : unknown

---

[1] Please list the insecticides (four or five) most frequently used on sorghum in your state, in decreasing order of volume of use.

[2] Please list the most important insects, in decreasing order of importance, against which the listed pesticides are recommended and used.

PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop Corn :

Type of Pesticide: Insecticides

Year : 1974

State: Nebraska

		Pound Active Ingredient Per Acre			
		Recommended			
Pesticide[a]	Target Pest(s)[b]	By Extension Service	By Suppliers	Generally Used by Growers	Minimum Effective Rate
Carbofuran	corn rootworms	1 Lb.	.75-1.0 Lb.	0.8 - 1.0	0.75
Phorate	corn rootworms	1 Lb.	1 Lb.	1 Lb.	
Dasanit©	" "	1 Lb.	1 Lb.	1 Lb.	
Dyfonate©	" "	1 Lb.	1 Lb.	1 Lb.	

Total Acreage Versus Acreage Treated with Insecticides in the State

Approximate number of acres in your state (1974) -

- Planted: 5,890,000
- Harvested for grain: 4,250,000
- Needing insecticide treatment: Not known
- Actually treated at least once : 3,690,000

1/ Please list the insecticides, (four or five) most frequently used on corn, in your state, in decreasing order of volume of use.

2/ Please list the most important insects in decreasing order of importance, against which the listed pesticides are recommended and used.

PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop Sorghum

Type of Pesticide: Insecticides

Year : 1974

State: Nebraska

Pesticide[a/]	Target Pest(s)[b/]	Pound Active Ingredient Per Acre			
		Recommended		Generally Used by Growers	Minimum Effective Rate
		By Extension Service	By Suppliers		
Ethyl parathion	greenbugs	0.5 Lb.	0.5 Lb.	0.5 Lb.*	0.5 Lb
Di-Syston®	greenbugs	0.25 Lb.	0.25 Lb.	0.25 Lb.*	0.25 Lb.
Dimethoate	greenbugs	0.38 Lb.	0.38 Lb.	0.38 Lb.	0.38 Lb.

* applied by aircraft - not by farmers

Total Acreage Versus Acreage Treated with Insecticides in the State

Approximate number of acres in your state (1974) -

- Planted: 2,275,000
- Harvested for grain: 1,865,000
- Needing insecticide treatment: not known
- Actually treated at least once 800,000 or less

1/ Please list the insecticides, (four or five) most frequently used on orghum in your state, in decreasing order of volume of use.

2/ Please list the most important insects, in decreasing order of importance, against which the listed pesticides are recommended and used.

PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop : Sorghum

Type of Pesticide: Insecticide

Year : 1974

State: New Mexico

		Pound Active Ingredient Per Acre			
		Recommended			
Pesticide[a]/	Target Pest(s)[b]/	By Extension Service	By Suppliers	Generally Used by Growers	Minimum Effective Rate
disulfoton E.C.	greenbug	0.375-0.5	0.375-0.5	0.375-0.5	0.5
disulfoton gran.	greenbug	1.0	0.75 - 1.0	0.75-1.0	1.0
disulfoton gran.	mites	1.0	1.0	1.0	1.0
phorate gran.	greenbug	1.0	0.75-1.0	0.75-1.0	1.0
phorate gran.	mites	1.0	1.0	1.0	1.0
parathion E.C.	greenbug	0.5	0.5	0.5	1.0
dimethoate E.C.	greenbug	0.33-0.5	0.33-0.5	0.33-0.5	0.5

Total Acreage Versus Acreage Treated with Insecticides in the State

Approximate number of acres in your state (1974) -

- Planted: 500,000-260,000 irrigated
  240,000 dry land
- Harvested for grain:
  225,500 irrigated 180,000 dry lan
- Needing insecticide treatment: 350,000
- Actually treated at least once with any insecticide
  250,000

1/ Please list the insecticides, (four or five) most frequently used on sorghum in your state, in decreasing order of volume of use.

2/ Please list the most important insects , in decreasing order of importance, against which the listed pesticides are recommended and used.

PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop : Apples

Type of Pesticide: Fungicides

Year : 1974

State: NEW YORK

		Pound Active Ingredient Per Acre (or per 100 gal.)				
		Recommended		Generally	Minimum	Total Acreage Versus Acreage
Pesticide[a/]	Pest(s)[b/]	By Extension Service	By Suppliers	Used by Growers	Effective Rate	Treated with Fungicides in the State
captan	*apple scab*	*14 appl. @ 3 ℓb/A*	*?*	*?*	*6-14 appl. @ 1.5-3 ℓb/A*	Approximate number of acres of apples in your state
dodine	*apple scab*	*14 appl. @ 0.73 ℓb/A*	*?*	*?*	*6-14 appl. @ 0.73 ℓb/A*	
sulfur	*powdery mildew*	*8 appl. @ 6 ℓb/A*	*?*	*?*	*6-8 appl. @ 4-6 ℓb/A*	- Total *72,000*
maneb/zinc coordination product	*apple scab*	*14 appl. @ 4.8 ℓb/A*	*?*	*?*	*6-14 appl. @ 2.4-4.8 ℓb/A*	- Needing fungicide treatment: *72,000*
	rust	*6 appl. @ 1.8 ℓb/A*	*?*	*?*	*4-6 appl. @ 1.8 ℓb/A*	
benomyl plus spray oil	*apple scab*	*14 appl. @ 0.25 ℓb/A*	*?*	*?*	*6-14 appl. @ 0.25 ℓb/A*	- Actually treated at least once with any fungicide: *72,000*
	powdery mildew	*8 appl. @ 0.25 ℓb/A (plus 3-4 quarts spray oil per acre)*	*?*	*?*	*6-8 appl. @ 0.25 ℓb/A*	

1/ Please list the fungicides (four or five) most frequently used on apples in your state, in decreasing order of volume of use.

2/ Please list the most important diseases, in decreasing order of importance, against which the listed pesticides are recommended and used.

PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop : Apples
Type of Pesticide: Insecticides
Year : 1974

State: New York
– Brann Jr

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		Pound Active Ingredient Per Acre (or per 100 gal.)			
		Recommended		Generally Used by Growers	Minimum Effective Rate
Pesticide[a]	Pest(s)[b]	By Extension Service	By Suppliers		
Guthion 50WP Imidan 50WP Zolone 3EC	Plum curculio Codling moth Apple maggot Red Banded leaf roller Misc. other insects	¾-1 lb 1½-2 lb. 1⅓-1¾ pts	Same " "	* Same to 30% less depending on insect pressure.	* * " "
Oil	European Red mite San Jose Scale	4-8 gals	"		" "
Systox	Aphids, E.R. mite Misc. other insects	1 pt.	"		"

Total Acreage Versus Acreage Treated with Insecticides in the State

Approximate number of acres of apples in your state

- Total 75,000
- Needing insecticide treatment: 75,000
- Actually treated at lea t once with any insecticide
  - : 75,000

1/ Please list the insecticides (four or five) most frequently used on apples in your state, in decreasing order of volume of use.

2/ Please list the most important insects and mites , in decreasing order of importance, against which the listed pesticides are recommended and used.

* See indicated paragraph page 2 of enclosed 1973 Tree Fruit Production Recommendations

** Same as Extension recommendations for heavy or potentially heavy infestations. 10 to 30% less where insects are well under control.

PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop : Apples

Type of Pesticide: Fungicides

Year : 1974

State: North Carolina

		Pound Active Ingredient Per Acre (or per 100 gal.)			
		Recommended			
Pesticide[a/]	Pest(s)[b/]	By Extension Service	By Suppliers	Generally Used by Growers	Minimum Effective Rate
Captan	scab, black rot, white rot, bitter rot, sooty blotch	The Extension Service makes no recommendations. It provides information	--	Yes	2 lb
maneb	bitter rot, black rot, white rot, scab, rusts, sooty blotch			yes	2 lb
dodine	scab			yes	1/2 lb.
benomyl	scab, black rot, white rot, mildew, sooty blotch			yes	6 oz.
·folpet	black rot, white rot			yes	2 lb.

Total Acreage Versus Acreage Treated with Fungicides in the State

Approximate number of acres of apples in your state

- Total : 20,000
- Needing fungicide treatment: 20,000
- Actually treated at least once with any fungicide: 20,000

1/ Please list the insecticides/fungicides (four or five) most frequently used on apples in your state, in decreasing order of volume of use.

2/ Please list the most important insects and mites/diseases, in decreasing order of importance, against which the listed pesticides are recommended and used.

ferbam	bitter rot, scab, sooty blotch rusts (quince and cedar apple)			yes	2 lb.
sulfur	powdery mildew			yes	2 lb.
dinocap	powdery mildew			yes	1/4 lb.
thiram	rusts, fruit rots			yes	2 lb.

PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop : Apples

State: North Carolina

Type of Pesticide: Insecticide - Fungicide - Miticide

Year : 1974

, Pesticide[a]/	Pest(s)[b]/	Pound Active Ingredient Per Acre (or per 100 gal.)				Total Acreage Versus Acreage Treated with Insecticides/ Fungicides in the State
		Recommended		Generally Used by Growers	Minimum Effective Rate	
		By Extension Service	By Suppliers			
Guthion 50 W	CM, RBLR, AM	1/2 lb	1/2 lb	1/2 lb	1/2 lb	Approximate number of acres of apples in your state
Lead Arsenate WP	CM, RBLR, AM Diseases	2 lb	2 lb	2 - 3 lb	2 lb	
Parathion 15W	CM, RBLR, AM	2 lb	2 lb	2 lb	2 lb	- Total 1,110,354 trees $13.1 million
Phosphamidon 8E	Aphids	2 1/2 oz	2 1/2 oz	2 1/2 oz	2 1/2 oz	- Needing insecticide/ fungicide treatment: All
Captan 50 W	Scab, Rots	2 lb	2 lb	2 lb	2 lb	
Polygram 80 WP	Scab, Rusts Rots	2 lb	2 lb	2 lb	2 lb	- Actually treated at least once with any insecticide/ fungicide: All
Oil	Mites	2 gal	2 gal	2 gal	2 gal	

1/ Please list the insecticides/fungicides (four or five) most frequently used on apples in your state, in decreasing order of volume of use.

2/ Please list the most important insects and mites/diseases, in decreasing order of importance, against which the listed pesticides are recommended and used.

PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64
Attn: K. A. Lawrence

Crop : Apples
Type of Pesticide: Fungicides
Year : 1974

State: Ohio

		Pound Active Ingredient Per Acre (or per 100 gal.)			
		Recommended		Generally Used by Growers	Minimum Effective Rate
Pesticide[a/]	Pest(s)[b/]	By Extension Service	By Suppliers		
Captan	Ventuna inaequalis Physalospora obtusa Glomerella cingulata Gloeodes pomigena Mycosphaerella pomi Botryosphaeria ribis	1.6-3.2 lbs depending on season	Same	Same	same
Zineb	above plus Gymnosporangium spp	2.4 lbs	3.4	3.4	2.4
Dikar	above plus Podosphaera leucotricha	4-5 lbs	Same Depending on	same season	same
Dodine	Venturia inaequalis Physalospora obtusa	0.4-1 lb	same Depending on	same weather & season	same
Polyram	same as for captan + zineb	5.4 lbs	same	same	Same

Total Acreage Versus Acreage Treated with - Fungicides in the State

Approximate number of acres of apples in your state

- Total 15,000.
- Needing fungicide treatment: All
- Actually treated at least once with any fungicide: All

1/ Please list the fungicides (four or five) most frequently used on apples in your state, in decreasing order of volume of use.

2/ Please list the most important diseases, in decreasing order of importance, against which the listed pesticides are recommended and used.

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PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop : Corn
Type of Pesticide: Herbicide
Year : 1974
State: Ohio

		Pound Active Ingredient Per Acre			
		Recommended			
Pesticide[a]	**Target Pest(s)**[b] *	**By Extension Service**	**By Suppliers**	**Generally Used by Growers**	**Minimum Effective Rate**
Atrazine	BL & Gr	1½ to 4	1½ to 4	1½ to 4	**
Alachlor	Gr	2 to 3	2 to 3	2 to 3	**
Simazine	BL & Gr	1½ to 4	1½ to 4	1½ to 4	**
Butylate	Gr	3 to 4	3 to 4	3 to 4	**
2,4-D	BL	¼ to ½	¼ to ½	¼ to ½	**

* BL = broadleaf annuals; Gr = annual grasses

** Depends on soil type, weed species and severity of weed infestation

Total Acreage Versus Acreage Treated with Herbicides in the State

Approximate number of acres in your state (1974) - 3.1 mil

- Planted: 3.1 mil
- Harvested for grain: 2.[illegible] mil
- Needing herbicide treatment: 3 mil
- Actually treated at least once with any herbicide: 2.7 mil

1/ Please list the herbicides (four or five) most frequently used on corn in your state, in decreasing order of volume of use.

2/ Please list the most important weeds, in decreasing order of importance, against which the listed pesticides are recommended and used.

PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop : Apples   State: OHIO

Type of Pesticide: Insecticide (only)

Year : 1974

→ Pound ~~Active Ingredient~~ formulated insecticide Per Acre (or per 100 gal.)

Pesticide[a]/	Pest(s)[b]/	Recommended By Extension Service	Recommended By Suppliers	Generally Used by Growers	Minimum Effective Rate
378 1. Guthion 50WP	Codling moth Plum Curculio leafrollers	2 lbs.	[illegible] varying by [illegible] [illegible], though are recommendations	Same as above.	
2. Imidan 50WP	Codling moth Plum Curculio leafrollers	4-6 lbs.			
3. Sevin 50WP	Codling moth apple maggot leafrollers	4-8 lbs.			
4. Zolone 3EC	Codling moth apple maggot leafrollers	3-16 pts.			
5. Systox 6EC	aphids [illegible]	1-2.5 pts.			

Total Acreage Versus Acreage Treated with Insecticides in the State

Approximate number of acres of apples in your state: Ohio 15,000 A

- Total
- Needing insecticide treatment: 90-95%
- Actually treated at least once with any insecticide 85-90%

[1]/ Please list the insecticides (four or five) most frequently used on apples in your state, in decreasing order of volume of use.

[2]/ Please list the most important insects and mites, in decreasing order of importance, against which the listed pesticides are recommended and used.

PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop Sorghum :
Type of Pesticide: Herbicides
Year : 1974

State: OKLAHOMA

		Pound Active Ingredient Per Acre			
		Recommended			
Pesticide[a]	Target Pest(s)[b]	By Extension Service	By Suppliers	Generally Used by Growers	Minimum Effective Rate
2,4-D	Pigweed, kochia	1/3	1/3	1/3	1/3
Propazine	Pigweed, crabgrass	1 - 3	1 - 3	1 - 2	Minimum rate depends on soil type for a preemergence herbicide
Igran	Pigweed, crabgrass	1 - 2½	1 - 2½	1 - 2	
Atrazine	Pigweed, crabgrass Barnyardgrass mustard	1 - 3	1 - 3	1 - 2	

Total Acreage Versus Acreage Treated with Herbicides in the State

Approximate number of acres in your state (1974) -

- Planted: 1,000,000
- Harvested for grain: 850,000
- Needing herbicidal treatment: 500,000
- Actually treated at least once with any herbicides 800,000

Igran used on sandy soil, atrazine used a little preemergence, but mostly early postemergence in Oklahoma.

1/ Please list the herbicides (four or five) most frequently used on corn/sorghum in your state, in decreasing order of volume of use.

2/ Please list the most important weeds, in decreasing order of importance, against which the listed pesticides are recommended and used.

PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop Corn :

Type of Pesticide: Herbicide

Year : 1974

State: South Dakota

		Pound Active Ingredient Per Acre			
		Recommended			
Pesticide[a]	Target Pest(s)[b]	By Extension Service	By Suppliers	Generally Used by Growers	Minimum Effective Rate
alachlor	Ann. grass	2-3			
propachlor	Ann. grass	4-5½			
atrazine	Ann. Broadleaved	1-3			
2,4-D	Broadleaved	½-1			
dicamba	Broadleaved	½			

Total Acreage Versus Acreage Treated with Herbicides in the State

Approximate number of acres in your state (1974) -

- Planted:

- Harvested for grain:

- Needing herbicide treatment:

- Actually treated at least once with any herbicide:

1/ Please list the 'herbicides (four or five) most frequently used on corn,' in your state, in decreasing order of volume of use.

2/ Please list the most important weeds, in decreasing order of importance, against which the listed pesticides are recommended and used.

PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop Grain Sorghums

Type of Pesticide: Herbicide

Year : 1974

State: South Dakota

		Pound Active Ingredient Per Acre			
		Recommended			
Pesticide[a]	Target Pest(s)[b]	By Extension Service	By Suppliers	Generally Used by Growers	Minimum Effective Rate
2,4-D	Broadleaved	¼-½			
propachlor	Ann. Grass	4-5			
atrazine	Ann. Broadleaved	1¼			
propazine	and grass	2			

Total Acreage Versus Acreage Treated with Herbicides in the State

Approximate number of acres in your state (1974) -

- Planted:
- Harvested for grain:
- Needing herbicide treatment:
- Actually treated at least once with any herbicide:

1/ Please list the herbicides (four or five) most frequently used on corn/sorghum in your state, in decreasing order of volume of use.

2/ Please list the most important 'weeds, in decreasing order of importance, against which the listed pesticides are recommended and used.

PESTICIDE APPLICATION DATA

Return to:

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
Attn: K. A. Lawrence

Crop : Apples
Type of Pesticide: Insecticides
Year : 1974

State: Washington

		Pound Active Ingredient Per Acre (or per 100 gal.)			
		Recommended			
Pesticide[a]	Pest(s)[b]	By Extension Service	By Suppliers	Generally Used by Growers	Minimum Effective Rate
1) Spray oil	Scale, mites	↘ ↙ Generally agree, however our rates for guthion are lower			
2) Guthion®	Codling moth				
3) Parathion	Scale, aphids				
4) Sevin®	just for Thinning				
5) Thiodan®	aphids				

Total Acreage Versus Acreage Treated with Insecticides/ Fungicides in the State

Approximate number of acres of apples in your state

- Total 92,500 Acres
- Needing insecticide/ fungicide treatment:
- Actually treated at least once with any insecticide/ fungicide:

1/ Please list the insecticides/fungicides (four or five) most frequently used on apples in your state, in decreasing order of volume of use.

2/ Please list the most important insects and mites/diseases, in decreasing order of importance, against which the listed pesticides are recommended and used.

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